INSTITUTE OF PAPER CHEMISTRY
Appleton · Wisconsin

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK MIXTURES

Project 3212

Report Eight
A Progress Report
to
MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

January 30, 1977

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SUMMARY

Black spruce has a wood specific gravity of 0.40 and an average bark specific gravity of 0.42. Bark extractives levels average 14.7%. Morphologically, the bark contains large numbers of sieve cells, some sclereids but no fiber. Pulping black spruce bark gave a solids yield of 26%. Hammermilling and screening resulted in only an intermediate reduction in levels of bark, 26% bark removal and 6% wood loss. Water flotation would not work with this species as the wood and bark were very similar in density at various moisture contents. Wood/bark adhesion measurements were unusually high considering the lack of fiber in the bark.

Red alder, based upon values in the literature and measurement data obtained from trees sampled as part of the project, has an average wood specific gravity of 0.37 and a bark specific gravity of 0.58. Extractives levels for wood and bark were 2.1 and 6.0%, respectively. Pulping red alder bark produced a solids yield of approximately 27%. Screening the bark resulted in 89% of the solids passing through the 200-mesh screen. Based upon these results, it appears bark would have little influence on the pulp produced from a chip mixture. Hammermilling resulted in a 48% reduction in levels of bark with an 8% wood loss. This is the highest reduction in bark levels obtained so far. Water flotation also worked well with this species with segregation possible at moisture contents of approximately 60% to 160% (ovendry basis).

Northern black cottonwood was found to have a wood specific gravity of 0.32 and a bark specific gravity of 0.40. Extractives levels were 2.3 and 20.6%,

respectively, for the wood and the bark. The bark, when pulped, had a solids yield of approximately 26%. Screening the bark resulted in 12% phloem fibers and 0.1% sieve tubes being produced. Hammermilling gave intermediate results with a 26% reduction in levels of bark and a 5% wood loss. However, a useful approach might be to make a quick segregation by screening, hammermilling or shredding the fractions high in bark and rescreening. Also, deliberate degradation of the bark before mechanical treatment appears to have some promise as a method of reducing bark levels. Water flotation would also work with this species with segregation possible at moisture contents of approximately 60% and above (ovendry basis).

Silver maple has a wood specific gravity of 0.42 and a bark specific gravity of 0.57. Extractives levels were 3.5 and 6.6%, respectively, for the wood and the bark. Morphologically, the bark contains mostly fiber and sclereids. The sclereids are branched, separate easily (more so than in the case of balsam fir, which also has branched sclereids) and should not cause any problem in paper. Pulping silver maple bark gave a solids yield of approximately 32%. Screening the pulp resulted in 5.9% phloem fibers, 2.5% sclereids and 0.6% sieve tubes remaining on the 60- and 100-mesh screens. Hammermilling resulted in only a 14% reduction in bark levels and a 4% wood loss but a useful approach might be to make a quick segregation by screening, hammermilling or shredding the fractions high in bark and rescreening. Water flotation is also a feasible technique for this species with segregation possible at moisture contents of between 40-50% and 115% (ovendry basis).

Added again in this report is a section giving the Btu's, ash, calcium and silica levels for all 32 species. Another added feature is a table giving the modulus of elasticity for all species investigated.

INTRODUCTION

Progress Report Eight completes the bark characterization research for an agreed-upon total of 32 pulpwood species. The work was initiated originally as a group project in 1973 and then switched to an Institute funded project in 1974. The wood raw material situation has changed rapidly the past four years and it is of interest to examine the original objectives of the project and consider how the program has changed as the result of company input, pulpwood requirements and the energy crisis.

Preliminary experience in bark investigations under way at the Institute prior to 1973 made it evident that because of: (1) large between-species differences in bark characteristics, (2) company investments in harvesting, debarking and wood room equipment, (3) limited digester, cleaner and recovery system capacity, (4) use of species mixtures, and (5) differences in end product requirements, no universal solution to the bark problem was possible. An early statement of project objectives indicated the objective of the program was to supply Institute member companies with information on the fundamental properties of bark (and wood) of important pulpwood species. The information obtained on each species was expected to help companies determine the usefulness of a particular tree species as a raw material and assist in determining how the species might be best harvested and handled to obtain appropriate levels of wood/bark segregation. These original objectives have not changed but, as the whole-tree harvesting system developed, closed pulping systems were required, pulpwood shortages developed in 1974 and then disappeared in 1976, and the energy crisis developed, the bark problem became a whole new ball game.

Before the program had been under way more than a very few months, the decision was made that pulping of the bark should be investigated and, as a result, bark pulp yields and the nature of the fibrous material was made a part of the research program. Recovery boiler scaling problems prompted the addition of total ash, calcium and silica determinations to the program and the energy crisis made it appropriate to consider the fuel value of bark. Presently, because pulpwood is in good supply and mill problems have been greater than anticipated, the use of whole-tree chips has declined and interest in solving the problem has diminished.

Energy (harvesting, transporting, chipping, pulping, cleaning, beating, etc.) appears to be the key factor in the present wood/bark segregation picture. Delivery of the finished product to the consumer at the lowest energy output requires appropriate consideration be given maximum fiber utilization, minimum use of energy in harvesting and transporting as well as the increased manufacturing energy requirements associated with the use of low-quality fibrous raw materials. Bark has a considerable fuel value if handled by a dry process and appropriate consideration must be given to energy independence. A sure way to invite disaster is to sit on our hands when energy and wood raw materials are in good supply and not work on the problem. We should be going ahead as rapidly as possible to work out methods to effectively use whole-tree chips and be thankful for the time available before the next expected wood raw material shortage and energy crisis.

TREE GROWTH AND BARK DEVELOPMENT

Tree growth and bark development were covered in Project 3212, Progress Report One. To briefly summarize, a tree grows through elongation and enlargement of the bole and crown (primary growth) and thickening of the bole (secondary growth). The bark consists of the inner bark (secondary phloem), which is partly physiologically active, and the outer bark, which is mainly functionless. Tissues in the inner bark are constantly being developed and the first-formed layers of periderm may be cut off from the vital processes of the tree. This can result in roughened bark which may either be cast off or retained as in the case of deeply fissured trees. In smooth-barked trees the first-formed periderm may persist for many years. Figure 1, taken from Chang (1) illustrates the tissues found in different kinds of bark and is provided, along with the Glossary, to help the reader better understand the bark descriptions that follow.

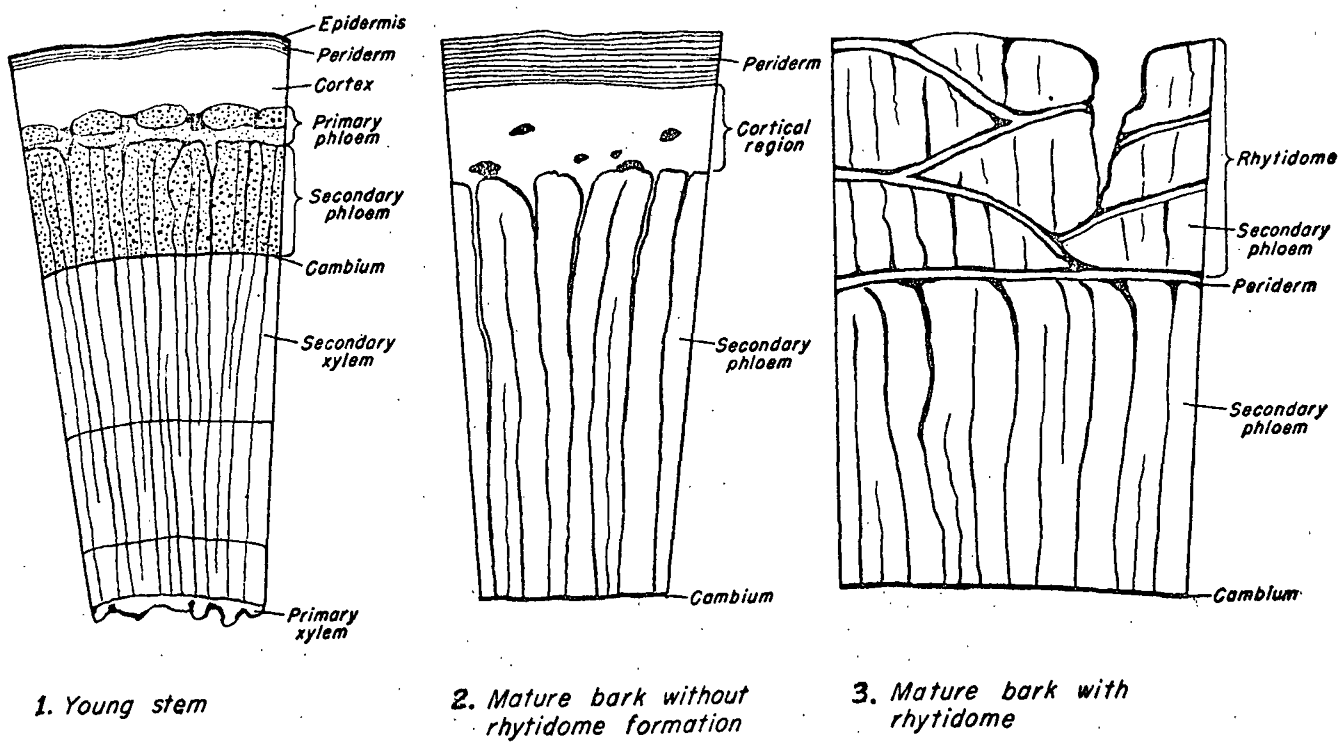


Figure 1. Diagrammatic Drawings Showing the Main Tissue in Different Types of Bark. (1) Cross Section of Young Branch or Stem. (2) Cross Section of Bark Having Persistent Cortex, Such as That in the Middle-aged Balsam Fir and Quaking Aspen. (3) Mature Bark with Rhytidome Formation

EXPERIMENTAL PROCEDURES

The experimental procedures employed have, as much as possible, been standardized and the same methods used for each tree species. Progress Report One should be referred to for complete descriptions of the experimental procedures used.

Tree size and sample location were standardized and utilized trees 7 to 9 inches in diameter at breast height (4-1/2 feet). All measurements were made on samples from the breast high location or from 12 to 18-inch bolts obtained from the area just below the breast high sample.

Specific gravity was determined using a water displacement technique that is a modification of the TAPPI Standard Method, T 18 m-53, and results are expressed in terms of ovendry weight/green volume. The bark micropulping procedure was that of Thode, et al. (2). After micropulping, the bark was rinsed, fiberized in a Waring Blendor and decanted on a sintered glass funnel. It was then put through a series of screens and the material on each screen examined for the type of cellular material it contained.

The wood/bark adhesion method measured shear parallel to the grain on a small, specially prepared sample using the Instron tester. Representative growing and dormant season adhesion samples were immersed in ethyl alcohol immediately after testing for later morphological examination.

Bark strength measurements were made using essentially the same procedure as used in measuring wood/bark adhesion (shear parallel to the grain). Bark toughness measured the energy required to rupture a small bark or wood sample by bending with a force parallel to the diameter of the tree. A "Micro Pulverizer" was modified to provide a hammermilling test on standard bark and wood chips. After the chips were fed through the pulverizer, they were separated on a series of soil screens and the percentage on each screen calculated.

Basic density of standard wood and bark chips at various moisture contents was determined using a pycnometer and the chemical, heptane, as the displacement medium. Moisture content was calculated as (wet wt.-o.d. wt.)/o.d. wt. Density was calculated as $(\underline{c} \cdot \underline{d})/[\underline{c}-(\underline{b}-\underline{a})]$ where:

$\underline{a}$ = weight of pycnometer + heptane

$\underline{b}$ = weight of pycnometer + heptane + chip

$\underline{c}$ = weight of chip (wet — before being placed in heptane)

$\underline{d}$ - density of heptane.

WOOD AND BARK PROPERTIES OF BLACK SPRUCE [*Picea mariana* (Mill.) B.S.P.]

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Black spruce, one of the most abundant conifers of northern North America and an important pulpwood species, spans the continent from Newfoundland and northeastern United States to northwestern Alaska. Although the climate may be generalized as cold and subhumid, there is a wide variation in both temperature and precipitation within this extensive range. Black spruce grows on both organic and mineral soils and is characterized as a northern interior lowland tree. However, local relief, affecting drainage and bog formation, is more important than absolute elevation. On the best sites, such as the Ontario Clay Belt, black spruce reaches heights of 90 ft. with diameters of 18 inches. In contrast, trees at the extreme northern part of the range may be 10-20 ft. tall with 1-2 inch diameters at 100-200 years of age.

WOOD AND BARK MORPHOLOGY

Wood

Black spruce wood cannot be separated with certainty from white, red, or Engelmann spruce in gross characteristics or minute anatomy. The wood is lustrous, nearly white to pale yellowish-brown with an indistinct heartwood. Growth rings are distinct, delineated by the contrast between the narrow darker latewood and the wider zone of the earlywood of the succeeding ring.

The xylem consists of radially aligned tracheids, uniseriate and fusiform rays, and longitudinal and transverse resin canals. The tracheids average 25-30 µm in diameter and 3.5 mm in length. Average cell wall thickness varies from earlywood fibers of less than 1.0 µm to latewood fibers which measure 3-4 µm.

Uniseriate rays, fine and numerous, are 1-16+ cells in height. Fusiform rays are scattered, with one or rarely two transverse resin canals, and up to 16+ cells in height. Ray tracheids are present in both types of rays and usually restricted to one row on the upper and lower margin. Resin canals, lined with 7-9 thick-walled epithelial cells, are often occluded with tylosoids in the heartwood. The larger longitudinal resin canals have a maximum diameter of 135 µm, and the transverse, usually less than 30 µm.

Bark

Black spruce bark is characterized by a scaly, almost shaggy appearance without distinct furrows. Greyish-black to brown scales exfoliate easily, sometimes exposing the golden yellow and olive hue of the newly-formed periderm. The gross structure of alternate layers of periderm and secondary phloem in the outer bark are clearly shown on cross section. The narrow inner bark, about 2/32-3/32 inch thick, is light creamy yellow, turning brown after exposure. Sporadic sclereid groups are visible to the naked eye. Comparatively thin, the total bark is generally about 1/4 inch thick and seldom over 1/2 inch thick. The outer bark was thicker on tree 3212-92 than it was on tree 3212-91. This was reflected in the percent outer bark by weight for the two trees with 3212-91 having 57% and 3212-92 78% outer bark. Figure 2 illustrates a cross section of inner and outer bark. Appendix Table XXIX describes the trees used in this study.

Anatomical Structure of Bark

Young bark consists of an epidermis, periderm, cortex and primary and secondary phloem. The epidermis is composed of a single layer of epidermal cells with thickened and cutinized walls beneath which lie a few layers of collenchymatous hypodermis. These cells are long and columnlike with unevenly thick walls forming irregular intercellular spaces. Directly beneath the hypodermis, periderm appears

Figure 2. Cross Sections of Black Spruce. Photograph on Bottom Shows Xylem (X), Cambium Zone (CZ), Sieve Cells (SC), and Sclereids (S). Photomicrograph on Top is a Cross Section Showing a Periderm Layer (P). Magnification — 75X

in 1-year-old branches as a few layers of thin-walled phellem cells and a layer of phellogen and phelloderm. Within the cortical region are cortical parenchyma cells and usually about 10-12 vertical resin canals in the very young stem or branch. Traces of primary phloem appear, followed by the secondary phloem, similar in structure to that of mature bark.

In mature bark, the periderm is composed of one layer of phellogen, 2-3 layers of phelloderm and many layers of phellem. The main part of the periderm is composed of alternate layers of thick and thin-walled cells. The thin-walled cells are rather uniform in shape and size, about 10-25 µm on radial dimension, with uniformly thick, suberized walls about 2 µm thick. The thick-walled cells, more variable in size and wall thickness, have lignified walls often more than 10 µm thick. A periderm in the rhytidome may consist of 3-5 alternate bands of 5-10 layers of each type of phellem cell. The outer bark is different from the inner bark by the additional development of periderm and more "lignified" cells with increased cell contents.

The inner bark of black spruce consists of sieve cells regularly aligned in radial rows interrupted by tangential lines of parenchyma and sclereids, and phloem rays and resin canals. Sieve cells in the inner bark vary in length from 1.42 mm to 4.38 mm, averaging about 3.324 mm, and are gradually pointed at both ends. In cross section, sieve cells appear rectangular in shape, usually 20 µm in radial dimension and 40 µm in tangential dimension with uniformly thick walls, about 2 µm thick. In the outer bark, the sieve cells are mostly deformed and generally much shorter. About the same size and shape as the sieve cells on cross section, but with a slightly expanded radial dimension, parenchyma are aligned in tangential lines usually one cell thick. Individual cells, usually about 150 µm high, form strands about the same length as the adjacent sieve cells. Parenchyma cells often contain abundant "tanniferous" substances and single calcium oxalate crystals about 10 µm in diameter. Crystals were found in the innermost periderm of the trees examined in this project, which is the boundary between the inner and outer bark. Originating from the parenchyma, sclereids aggregate in small groups aligned more or less in discontinuous tangential lines. The individual cells are irregular in shape and branched with very thick walls. Laminate layers on the secondary walls and simple pits are distinct. The size of the sclereid groups vary but in general the radial dimension may be up to 150 µm, tangential, up to 1 mm, and height, 1-2 mm. Phloem rays are both uniseriate and fusiform. Uniseriate rays are generally 10-15 cells or 100-200 µm high. Albuminous cells are present in almost every ray close to the cambial zone. Fusiform rays containing horizontal resin canals lined with thin-walled epithelial cells are common. There are no fiberlike elements in the bark of black spruce.

To compare with species of white, red and Sitka spruce, the bark of black spruce is distinguished by its olive green to bright yellow-colored periderm; the number of sieve cells between two parenchyma lines; and the rather constant amount of sclereids in both the inner and outer bark.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures.* Wherever possible, data on bark have been compared with similar information on wood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

Specific Gravity

Table I summarizes the information available on wood and bark of black spruce. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that one of the values in the table is ovendry weight divided by ovendry volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of black spruce at several moisture contents.

TABLE I

BLACK SPRUCE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Av.	Bark Inner	Bark Outer	Bark Total	References and Remarks
0.38				Bendtsen (2)
0.43				Maeglin (3)
0.42 (4.6-8.9 in. diam.)				Wahlgren, *et al*. (4)
0.40 (7.6-8.9 in. diam.)				Pronin (5)
0.40				Isenberg (6)
0.38				IUFRO (7)
	0.26	0.43	0.37	Fournier & Goulet (8)
0.40 (last-formed sapwood)	0.26	0.42	0.35	Lamb & Marden (9)
0.47 (exterior wood) 0.40 (interior wood)	0.42	0.53	0.52	IPC 3212-91
0.39 (exterior wood) 0.37 (interior wood)	0.38	0.44	0.43	IPC 3212-92
0.45[a]				Isenberg (6)

[a]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.40 appears appropriate for the wood of black spruce. Our samples were divided into interior and exterior wood and specific gravity determinations made on each. For 3212-91, the interior wood constituted the first 29 rings out of a total 59 rings and the first 25 rings out of a total 60 rings for 3212-92. Our limited data show the exterior wood to be slightly higher than the interior wood in specific gravity.

The specific gravity of the total (inner + outer) bark of black spruce is very close to that of the wood. The outer bark was higher in specific gravity than the inner bark on the two trees examined in this project and was confirmed by several literature values. Overall values suggested for use in species comparisons are 0.40 for wood and 0.33, 0.46 and 0.42 for inner, outer and total bark. These values are slightly higher in all cases than those obtained for white spruce (Report Three).

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists on alcohol-benzene extractives levels of both black spruce wood and bark. Table II summarizes existing data and includes the two IPC trees examined. Black spruce wood is low in extractives and a level of 1.5% is suggested for use in between-species comparisons. Extractives work done on black spruce bark in this project plus an additional value showed an average level of 14.7%. This is a relatively high level but should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques. Extractives levels for black spruce were slightly lower than those obtained for white spruce.

TABLE II

BLACK SPRUCE ALCOHOL-BENZENE EXTRACTIVES

Type of Material[a]	Extractives, %	Sources
Wood	1.0	Fengel & Grosser (10)
Wood	2.2	Isenberg (6)
Wood	2.5	IPC 3212-91
Wood	1.3	IPC 3212-92
Wood	0.6	Rydholm (11)
Bark	19.6	Chang & Mitchell (12)
Bark	10.4	IPC 3212-91
Bark	14.2	IPC 3212-92

[a]IPC determinations based upon airdry samples.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of black spruce having an effect on the pulp are sieve cells and sclereids. There are no fibers in the bark of black spruce.

The short, thin-walled sieve cells (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve cells, would probably be extremely brittle and low in strength. Sieve cells could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem. Using cross sections, Chang (1) estimated that sieve cells made up 74.9% of the tissue elements of the secondary phloem of black spruce.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. Estimates made of IPC samples suggest that sclereids make up 7-9% of the total bark weight after pulping. This is a low level and sclereids should not be much of a problem when the bark of black spruce is included in a pulp mixture. Chang (1) estimated that sclereids made up

2.4% of the secondary phloem (unmacerated cross sections) of black spruce. The sclereids are found in small, scattered groups (13).

As a check on pulp yield and the nature of the material produced from black spruce, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table III summarizes the results of this investigation. Micropulping black spruce bark resulted in a yield of 24 to 28% solids. When screened, the coarse screens (60 and 100 mesh) retained many of the sieve cells and a smaller percentage of sclereids. The on 150-mesh screen contained mainly sclereids along with some sieve cells. The on 200-mesh and through 200-mesh screens had high percentages of thick-walled peridermal cells and smaller percentages of sclereids, thin-walled parenchymatous cells and sieve cells. Figure 3 illustrates the type of material on the 60- and 150-mesh screens. The sieve cells in the "on 60 mesh" photomicrograph were stained darker than usual to better show their morphology although they actually are very lightweight elements.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 26 grams of solids will result. Of this 26 grams, about 7.4 grams (7.4%) of sieve cells and 3.4 grams (3.4%) of sclereids will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

TABLE III

BLACK SPRUCE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-91	Sample No. 3212-92	Remarks[a]
Yield, % solids	28.1	24.6	
Fraction			
On 60 mesh, %	21.5	42.6	The fraction contained a large percentage of sieve cells (70-80%) with a smaller percentage of sclereids (20-30%) and a trace of peridermal cells (<1%). Average arithmetic length of the sieve cells was 1.79 mm
On 100 mesh, %	11.1	7.4	The fraction contained sieve cells (40-50%) and sclereids (50-60%) and a trace of thick-walled peridermal cells (<1%)
On 150 mesh, %	11.7	6.4	The fraction contained a large percentage of sclereids (60-70%), with smaller percentages of sieve cells (20-30%) and thick-walled peridermal cells (5-10%) and a trace of thin-walled parenchymatous cells (<1%)
On 200 mesh, %	7.7	5.6	The fraction contained thick-walled peridermal cells (30-40%), sclereids (30-40%), sieve cells (10-20%) and thin-walled parenchymatous cells (10-20%)
Through 200 mesh, %	48.0	38.0	The fraction contained thick-walled peridermal cells (40-50%), sclereids (20-30%), thin-walled parenchymatous cells (20-30%) and sieve cells (5-10%)

[a]Percentages given are on a dry weight basis.

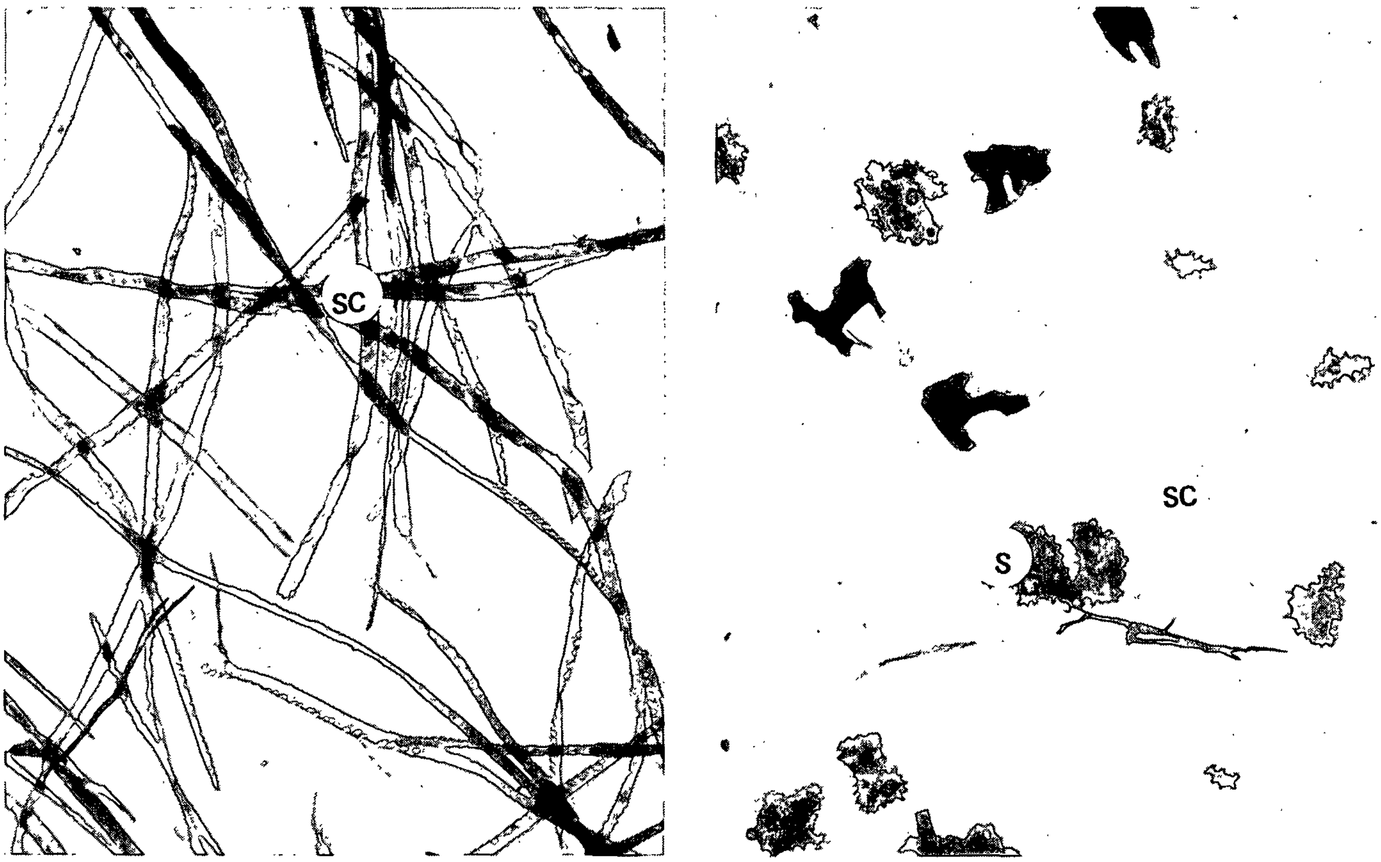


Figure 3. The 60-Mesh Screen (Left) Contained by Weight Principally Sieve Cells (70-80%) with a Smaller Percentage of Sclereids (20-30%). The 150-Mesh Screen (Right) Contained a Large Percentage of Sclereids (60-70%) with Smaller Percentages of Sieve Cells (20-30%). The Sieve Cells in the "On 60-Mesh" Photomicrograph (Left) were Stained Darker to Better Show Their Morphology Although they are Actually Very Thin-walled, Light-weight Elements, More Nearly as Illustrated by the "On 150-Mesh" Photomicrograph. Magnification — 75X. Symbols Illustrate Sieve Cells (SC) and Sclereids (S)

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in this study was to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for black spruce samples collected November 5 (dormant season). Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods, located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly formed xylem elements just outside the cambium zone.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 4 illustrates the zone of failure for black spruce during the dormant season. Failure occurred between cells in the cambium zone, located immediately adjacent to the last-formed latewood tracheids in the xylem. Adhesion measurements averaged 18.1 kg/cm^2, a very high value. The failure during the dormant season did not follow the usual pattern, i.e., failure in the secondary phloem in the proximity of the cambium zone. This is particularly unusual because of the high dormant season values. It is possible that in many other cases the break would occur in the secondary phloem and this should be taken into account when assessing the ease with which bark could be removed from chip mixtures.

As a result of measurement data taken on the species included in Appendix Table XXX and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology.

The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. However, despite the lack of phloem fibers and the presence of sclereids, bark strength for this species was high. The reason for this is unknown but may have been a factor in the failure zone occurring in the dormant cambium.

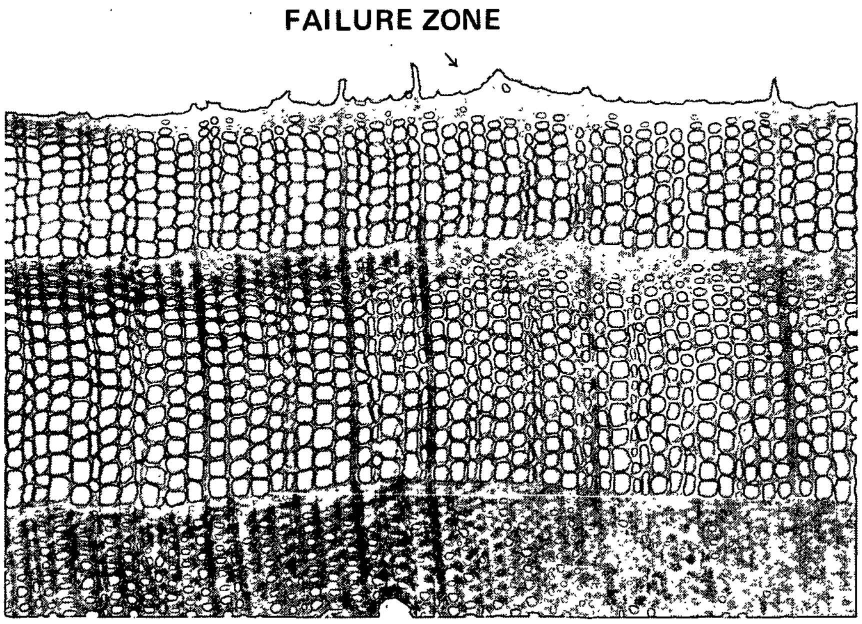


Figure 4. Illustrated is the Black Spruce Failure Zone on November 5. Failure Occurred Between Cells in the Cambium Zone, Located Immediately Adjacent to the Last-formed Latewood Tracheids in the Xylem. Magnification — 75X

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table IV summarizes the bark strength and toughness tests made on the wood and bark of black spruce. (Appendix Tables XXXII and XXXIII compare the modulus of elasticity of black spruce bark with other species examined in this project.)

TABLE IV

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF BLACK SPRUCE[a]

Material	Strength	Toughness
Wood	--	0.45
Inner bark	10.6	0.22
Outer bark	7.6	0.10

[a]Determinations average of two trees.

Bark strength values for black spruce inner bark were high compared to other softwoods tested thus far. Outer bark values were also high. Toughness values for both wood and bark were intermediate compared to other softwoods tested.

There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength result in good bark removal while low specific gravity and high toughness and strength give poor bark removal. Based upon the intermediate specific gravity of the bark and the high strength and intermediate toughness measurements, it appears that hammermilling would not work as well on this species as it has on some.

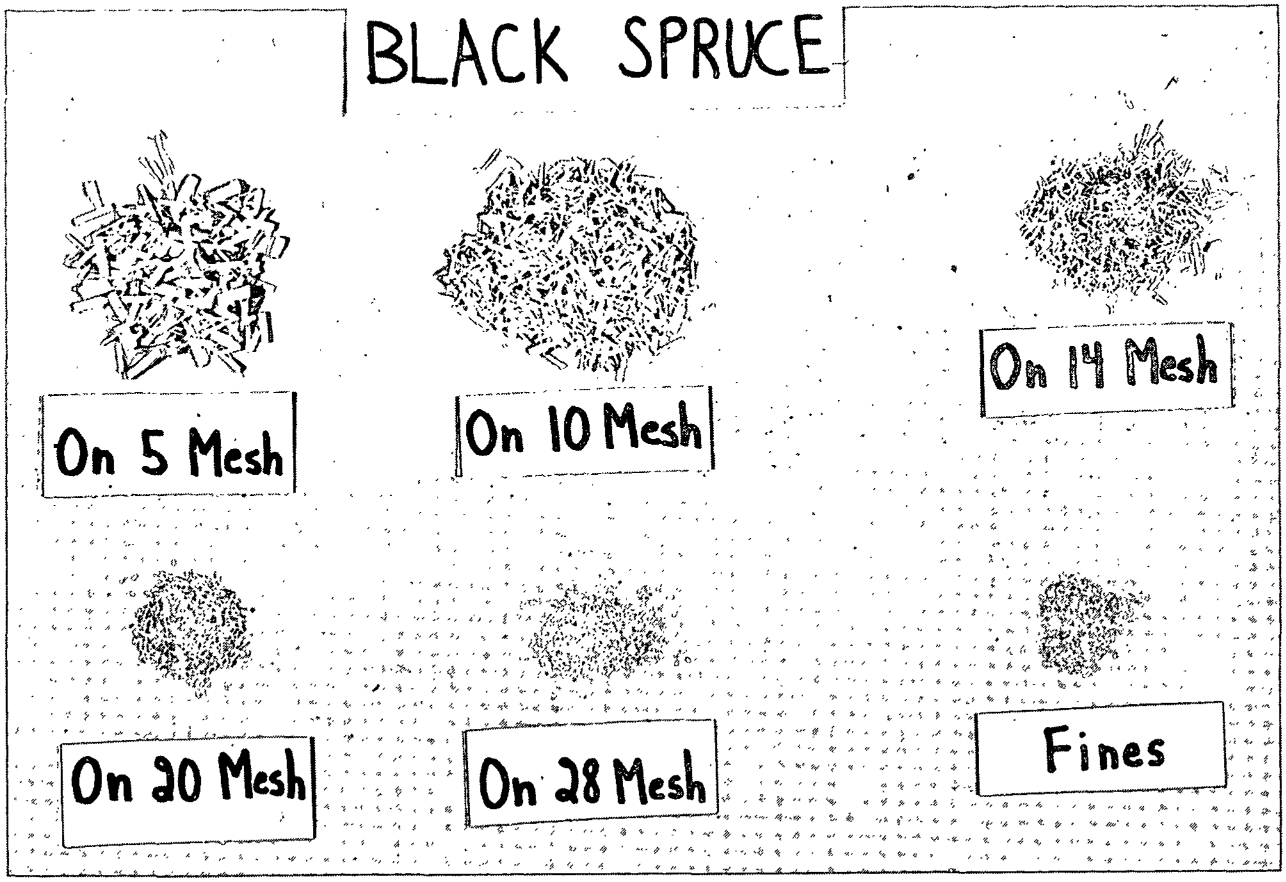
Summarized in Table V are the results of the hammermilling tests run on black spruce wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a moderate reduction in levels of bark, as predicted by the bark strength and toughness tests. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 6% wood loss and a 26% reduction in levels of bark. This is an intermediate reduction in bark compared to many of the other softwoods investigated thus far and quite similar to the results obtained for white spruce. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be greatly increased (44% bark removal and 15% wood loss). It seems doubtful that a wood loss this high is justified in view of the fact that the bark removal is still less than 50%. Depending upon the situation, however, it might be acceptable in view of the fuel value of the wood. Figure 5 illustrates the effect of hammermilling on wood and bark of black spruce. It is possible that a quick segregation could be made by screening, hammermilling or shredding the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible

TABLE V

SUMMARY OF HAMMERMILLING TEST ON BLACK SPRUCE

Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-91	Bark	19.9	32.2	20.8	7.3	6.9	12.9	Mostly inner bark on larger mesh screens with outer bark on smaller mesh screens. Some inner bark had tendency to sliver while other pieces stayed in rounded chunks
	Exterior wood	58.4	27.8	8.6	2.9	1.2	1.1	
	Interior wood	51.8	35.9	7.9	2.1	1.1	1.1	
3212-92	Bark	27.8	32.5	15.5	8.0	6.1	10.1	Same as above except that inner bark did not sliver as in 3212-91
	Exterior wood	51.6	29.1	11.6	3.5	2.3	1.9	
	Interior wood	46.0	38.9	9.8	2.0	1.6	1.8	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.



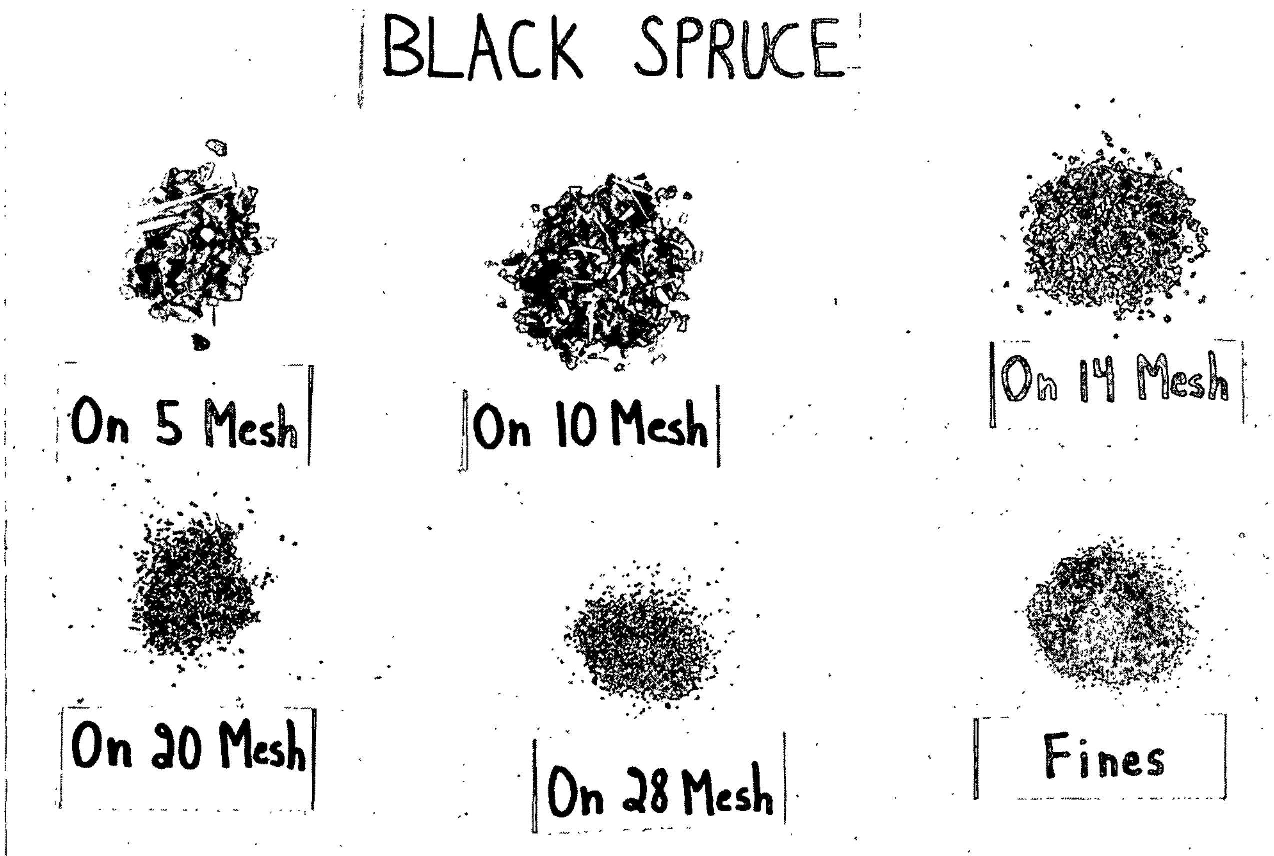


Figure 5. Illustrated is the Effect of Hammermilling on Black Spruce Wood (Top) and Bark (Bottom)

that improvements could be made in screening results by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 4 (14-16). This would require changes in screen design. Summary Table XXVII compares bark strength, toughness and reaction to hammermilling of black spruce with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two black spruce trees (IPC 3212-91 and IPC 3212-92) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Inner, outer and total bark were all very close in density at the various moisture contents.

Figure 6 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation is not possible for black spruce wood and bark chips. Both fractions would float at moisture contents of up to about 90% and are too similar in density at higher moisture contents. Also, work done previously in Project 2977 on white spruce showed that a pitch glaze on the bark tended to inhibit water uptake and ultimate sinking of bark chips.

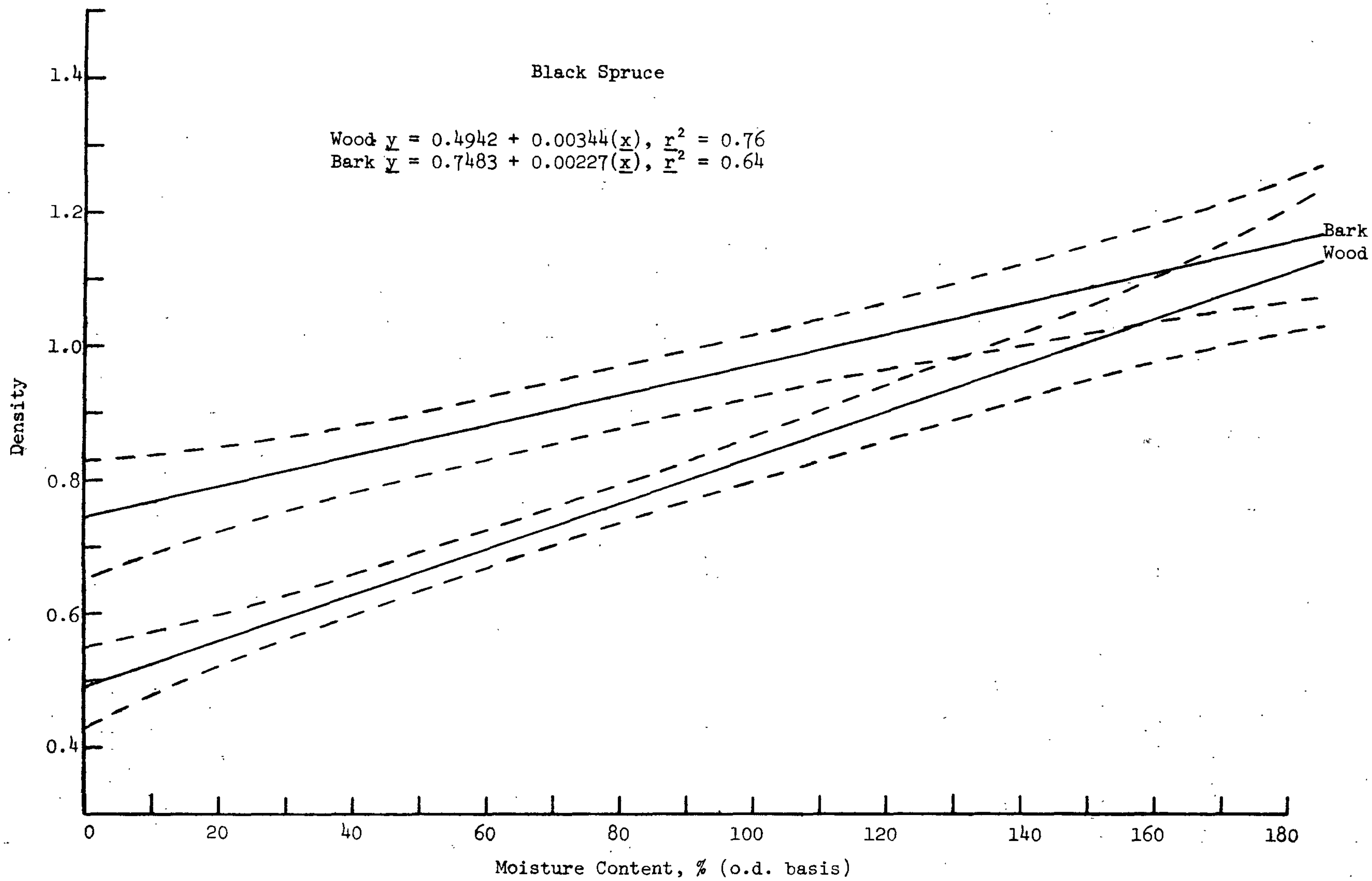


Figure 6. Illustrated is the Relationship Between Basic Density and Moisture Content for Black Spruce. The Dashed Lines are Two Standard Deviations Above and Below the Mean

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table VI summarizes the results for black spruce. These results agree with the results obtained in the density determination measurements which showed both wood and bark floating at 20% moisture content. Detached inner and outer bark would probably behave in a similar manner.

DATA INTERPRETATION

Since black spruce bark is high in extractives and both the inner and outer bark contain sclereids which can cause problems in certain grades of paper, it appears desirable to remove at least a portion of the bark. However, black spruce is a species in which it is difficult to suggest a separation and segregation technique. Segregation through water flotation would not work as the wood and bark are too similar in density at the various moisture contents. Despite the

TABLE VI

SUMMARY OF DWELL TIME RESULTS FOR BLACK SPRUCE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-91 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-91 Exterior wood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-91 Interior wood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-92 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-92 Exterior wood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-92 Interior wood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

lack of fiber in the bark of black spruce, dormant season wood/bark adhesion measurements were high. Failure occurred in the dormant cambium zone which, based upon the high adhesion measurements, may have been the weakest area. It is possible that a mechanical separation and segregation technique which would take advantage of failure in the cambium zone is the best approach for this species. Hammermilling and screening resulted in only an intermediate reduction in levels of bark, 26% bark removal and 6% wood loss, retaining the material on the 14-mesh or larger screens. Other types of mechanical separation and segregation, such as compression debarking, would bear investigation and may produce better results. Pulping black spruce bark resulted in 7.4 grams of sieve cells and 3.4 grams of sclereids being produced for every 100 grams of bark that is pulped. Black spruce bark contains no fiber.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (17), Hooper (18), Biltonen, et al. (19), Short, et al. (20), Miller (21) and Vais and Vostrov (22). A paper by Marden, et al. (23) contains information on moisture content and wood and bark percentages while the previously cited paper by Bendtsen (3) contains information on mechanical properties of black spruce.

WOOD AND BARK PROPERTIES OF RED ALDER
(Alnus rubra Bong.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Red alder, the most important hardwood of the Pacific Northwest, is the largest species of the genus. Its range is confined to the Pacific coast region from southeastern Alaska southward to latitude 34° in southern California. It is generally found no further inland than 100 miles and at elevations no higher than 2,500 ft. The coastal region supplies the high humidity or annual rainfall in excess of 25 inches that is required for good development. Temperature extremes vary greatly in the long north-south span with minimum temperatures below zero, or near zero for extended periods of time, limiting its range. Soils are not a serious limiting factor except as they affect soil moisture. The best stands however are found on deep, well-drained loams or loamy sands of alluvial origin. Alder plantings contribute to the physical and chemical improvement of soil as its nitrogen-rich foliage decomposes rapidly and soil fertility increases through symbiotic fixation of nitrogen by organisms contained in the root nodules. Soil nitrogen and growth rate of fir increase significantly in mixed plantings of alder and Douglas-fir. Maximum growth on better sites is 24-30 inches in diameter and 100-130 ft. in height with maximum volume on red alder stands obtained in 50-70 years.

WOOD AND BARK MORPHOLOGY

Wood

Red alder wood is straight grained and moderately light (sp.gr. approx. 0.37 green, 0.43 ovendry). With an indistinct heartwood, it is whitish when first sawed, aging to flesh color, and subject to oxidative sap stain. The wood is diffuse porous and growth rings are distinct. Small pores and narrow and broad rays are relatively inconspicuous to the naked eye. Vessels, parenchyma, fibers and rays form the wood structure. Vessels number 70-110 per sq. mm, with an average length of 0.85 mm and diameters up to 70-100 µm. Red alder vessels are readily separated from cottonwood and willow through the presence of scalariform perforation plates with 15+ bars. The intervessel pits are fairly small and quite widely spaced. Parenchyma are present in three forms. Paratracheal parenchyma are sparse and restricted to a few cells; metatracheal-diffuse are sparse to abundant as solitary cells or in short tangential rows; terminal parenchyma are occasionally present, forming an interrupted uniseriate line. Red alder fibers, thin to moderately thick-walled, have diameters of 16-40 µm and an average length of 1.19 mm. Rays are unstoried and homogeneous. Narrow rays are generally uniseriate and closely spaced. Aggregate rays, consisting of units similar to the narrow rays and included fibers and vessels, occur irregularly and often at wide intervals.

Bark

Red alder bark has been used locally as a tannin source in British Columbia where it was found to contain the maximum amount in March. The phenolic xyloside in the bark, with properties similar to phlobatannin, amounts to about 26.9% of the alcohol extract from the bark according to Kurth and Becker (24), and may be the chief cause of the red stain in the wood.

Red alder bark is thin, smooth and ashy-gray with frequent warty excrescences on the surface and yellowish to reddish-brown in areas where the inner bark is exposed. On old trees and the basal part of the trunk, the bark becomes rougher and tends to break into long shallow plates. On 35-year-old trees, approximately 10 inches in diameter, bark thickness averages about 0.2 inch. On cross section, there is a narrow layer of periderm, a narrow line of light yellow cortical sclerenchyma and a broad portion of reddish-brown secondary phloem with conspicuous light yellow sclereid groups more or less tangentially aligned, and aggregate phloem rays associated with those in the wood. According to the study by Chang (1), rhytidome formation was not found in the bark. The outer bark (periderm) averaged 11% by weight. Figure 7 illustrates a cross section of inner and outer bark. Appendix Table XXIX describes the trees used in this study.

Anatomical Structure of Bark

In very young trees or twigs, the bark is composed of a periderm with thin-walled, suberized phellem cells, phellogen and approximately two layers of phelloderm. It also contains a cortical region with some sclereids bounded by a few layers of collenchyma cells, primary phloem tissues crushed within a band of sclerenchyma, and newly formed secondary phloem tissues in the arrangement of the mature bark. The cortical cells are parenchymatous and often contain tanniferous substances and occasionally solitary crystals. Lignified cortex cells and sclereids form the sclerenchyma band, and sporadic sclereids are found in the secondary phloem tissues.

The mature bark of red alder consists of a periderm, a persistent cortical region and the secondary phloem. Only one band of periderm, composed mainly of thin-walled phellem cells, appears in middle-age trees. Decomposed phellem cells, containing abundant large granules of unknown substances at the outer surface of the bark, may explain the spotted warty excrescences. The cells in the continuously developing layers of phellem are rectangular in cross and radial sections with a rather narrow radial diameter, often only 5 µm wide. The periderm band is completed by one layer of phellogen and 2-3 layers of thin-walled,

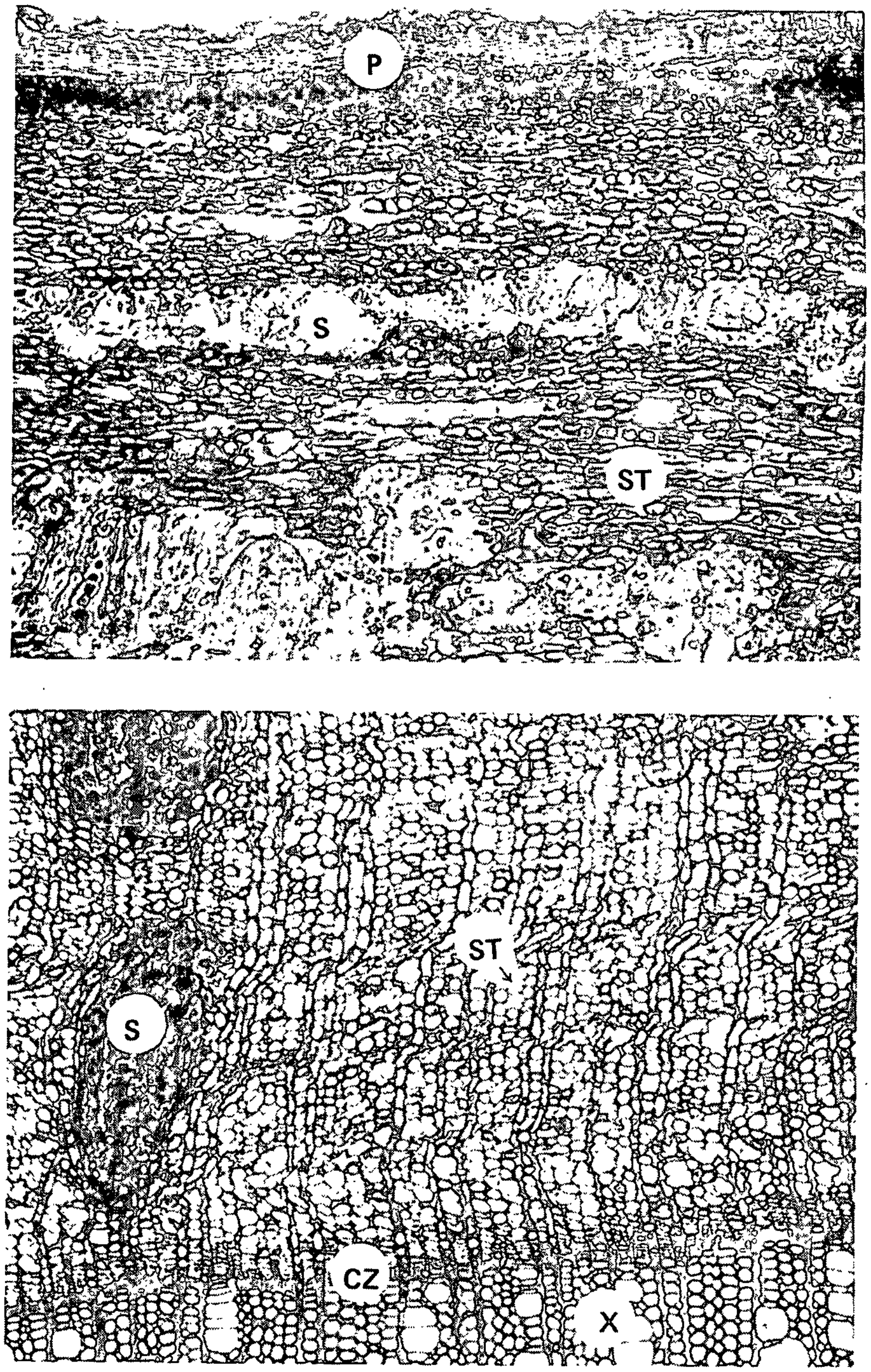


Figure 7. Cross Sections of Red Alder. Photograph on Bottom Shows Xylem (X), Cambium Zone (CZ), Sieve Tubes (ST), and Sclereids (S). Photomicrograph on Top Shows Sieve Tubes (ST), Bands of Sclerenchyma (S) and a Periderm Layer (P). Magnification — 75X

regularly aligned parenchymatous phelloderm cells that join with the cortex. In the mature tree, the cortical region is persistent with a zone of sclerenchyma as in the young stem.

The secondary phloem consists of sieve tubes, parenchyma, sclerenchyma and phloem rays. Sieve tubes, in 2-3 layers, are arranged in regular groups of 10-20, alternating with parenchyma bands and interrupted by sclereid-groups in the areas confined by the phloem rays. Retaining their original size and shape throughout most of the inner bark, they are long and cylindrical with sloping ends. Their tangential diameter varies from 30-60 μm and their total length, from 0.71-1.29 mm with an average length of 1.03 mm. Companion cells, in a strand of 6-8 cells, are often associated with the sieve tube elements at the narrow dimension. The older functionless sieve tubes often become "lignified." Phloem parenchyma, often containing tanniferous substances, are variable on cross section, from 10-20 μm in their radial dimension and 20-30 μm in tangential dimension, and usually 150 μm high in a strand. These cells may become lignified, retaining their original shape and cavity size, and sometimes become sclerotic, initiating the formation of sclereid-groups. Sclerenchyma in red alder bark is confined to three types of sclereids classified according to their origin. One group, initiated from transformed parenchyma and contiguous ray cells, usually form a few seasons' growth away from the cambium and increase in size by adding newly transformed cells to it. The second group, similar in composition and cell types, originate from transformed aggregate phloem rays. The cells in the entire ray become fully sclerified almost immediately away from the cambium and continuously develop as ordinary phloem rays in mature bark. Cortical sclereids, the third group, composed mainly of "lignified" cortex, are rather regular and uniform with very evenly thick walls. Red alder sclerenchyma does not contain any typical phloem fibers. Phloem rays in mature bark are both uniseriate and aggregate. The homogeneous uniseriate rays, often partially biseriate, are rather closely spaced and about 30 cells, 400 μm high. The aggregate rays, corresponding in size and position to the xylem aggregate rays, are composed of uniseriate rays, parenchyma and some deformed sieve tubes.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table VII summarizes the information available on wood and bark of red alder. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that one of the values in the table is ovendry weight divided by ovendry volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of red alder at several moisture contents.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

TABLE VII

RED ALDER SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Av.	Bark Inner	Bark Outer	Bark Total	References and Remarks
0.37				Isenberg (6)
0.37				IUFRO (7)
	0.52	0.62		Smith & Kozak (25)
0.41 (exterior wood) 0.35 (interior wood)	0.60	--[a]	0.59	IPC 3212-105
0.36 (exterior wood) 0.34 (interior wood)	0.54	--[a]	0.57	IPC 3212-108
0.43[b]				Isenberg (6)

[a]Too thin to test.
[b]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.37 appears appropriate for the wood of red alder. Our samples were divided into interior and exterior wood and specific gravity determinations made on each. For 3212-105, the interior wood constituted the first 20 rings out of a total 37 rings and the first 18 rings out of a total 36 rings for 3212-108. Our limited data show the exterior wood to be slightly higher than the interior wood in specific gravity.

The specific gravity of the total (inner + outer) bark of red alder is somewhat higher than that of the wood. Specific gravity measurements could not be obtained on the outer bark of the two trees studied in this project as it was too thin in both instances to obtain samples for measurement. One literature cited value showed the outer bark to be higher in specific gravity than the inner bark. Overall values suggested for use in species comparisons are 0.37 for wood and 0.55, 0.62 and 0.58 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists on alcohol-benzene extractives levels of both red alder wood and bark. Table VIII summarizes existing data and includes the two IPC trees examined. Red alder wood is low in extractives and a level of 2.1% is suggested for use in between-species comparisons. Extractives work done on red alder bark in this project plus two additional values showed an average level of 6.0%. This is a low level and indications are that extractives are not expected to be a serious problem when pulping the bark of this species.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal elements in the bark of red alder having an effect on the pulp are sieve tubes. There are no fibers in the bark of red alder and the sclereids are expected to have little effect on the pulp.

TABLE VIII

RED ALDER ALCOHOL-BENZENE EXTRACTIVES

Type of Material[a]	Extractives, %	Sources
Wood	2.8	Fengel & Grosser (10)
Wood	1.6	IPC 3212-105
Wood	1.8	IPC 3212-108
Bark	6.2	Chang & Mitchell (12)
Bark	6.2	Harkin & Rowe (26)
Bark	6.6	IPC 3212-105
Bark	4.8	IPC 3212-108

[a]IPC determinations based upon airdry samples.

The thin-walled sieve tubes (see photomicrographs) could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem. Using cross sections Chang (1) estimated that sieve tubes made up 35.4% of the tissue elements of the secondary phloem of red alder.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. Although Chang (1) estimated that sclereids made up 25.8% of the secondary phloem (based upon unmacerated cross sections), most of the sclereids in the IPC macerated samples ended up on the smaller mesh screens where they would have no effect on the pulp produced.

As a check on pulp yield and the nature of the material produced from red alder, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micro-pulping Procedure. Table IX summarizes the results of this investigation. Micro-pulping red alder bark resulted in a yield of 26 to 28% solids. When screened, the coarse screens (60 and 100 mesh) retained many of the sieve tubes and only a trace of other material. However, only about 4.5% of the total amount of solids was retained on these two screens. The on 150-mesh screen contained principally sieve tubes along with some parenchymatous cells. The on 200-mesh and through 200-mesh screens contained large percentages of parenchymatous cells with some sclereids and sieve tubes. The material passing through the 200-mesh screen averaged 89%. From these results, it seems likely that only a small amount of bark would remain in the pulp even if all the bark was pulped with the wood. Figure 8 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 27 grams of solids will result. Of this 27 grams, about 1.1 grams (1.1%) of sieve tubes and 0.1 gram (0.1%) of other material would be retained. This assumes that only the material on the

60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material, including most of the sclereids, would be lost in washing and cleaning operations.

TABLE IX

RED ALDER MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-105	Sample No. 3212-108	Remarks[a]
Yield, % solids	26.4	27.7	
Fraction			
On 60 mesh, %	0.0	0.5	The fraction contained principally sieve tubes (100-%) with a trace (<1%) of parenchymatous cells. Average arithmetic length of the sieve tubes was 0.92 mm
On 100 mesh, %	1.4	7.2	The fraction contained principally sieve tubes (95-100%) with a small percentage (<5%) of parenchymatous cells and a trace (<1%) of sclereids
On 150 mesh, %	3.1	1.2	The fraction contained large percentages of sieve tubes (60-70%) and parenchymatous cells (30-40%) and a trace (<1%) of sclereids
On 200 mesh, %	3.4	4.8	The fraction contained large percentages of sieve tubes (40-50%), parenchymatous cells (40-50%) with a small percentage of sclereids (10-20%)
Through 200 mesh, %	92.1	86.3	The fraction contained large percentages of parenchymatous cells (40-50%) and sclereids (40-50%) with a small percentage of sieve tubes (<5%)

[a]Percentages given are on a dry weight basis.

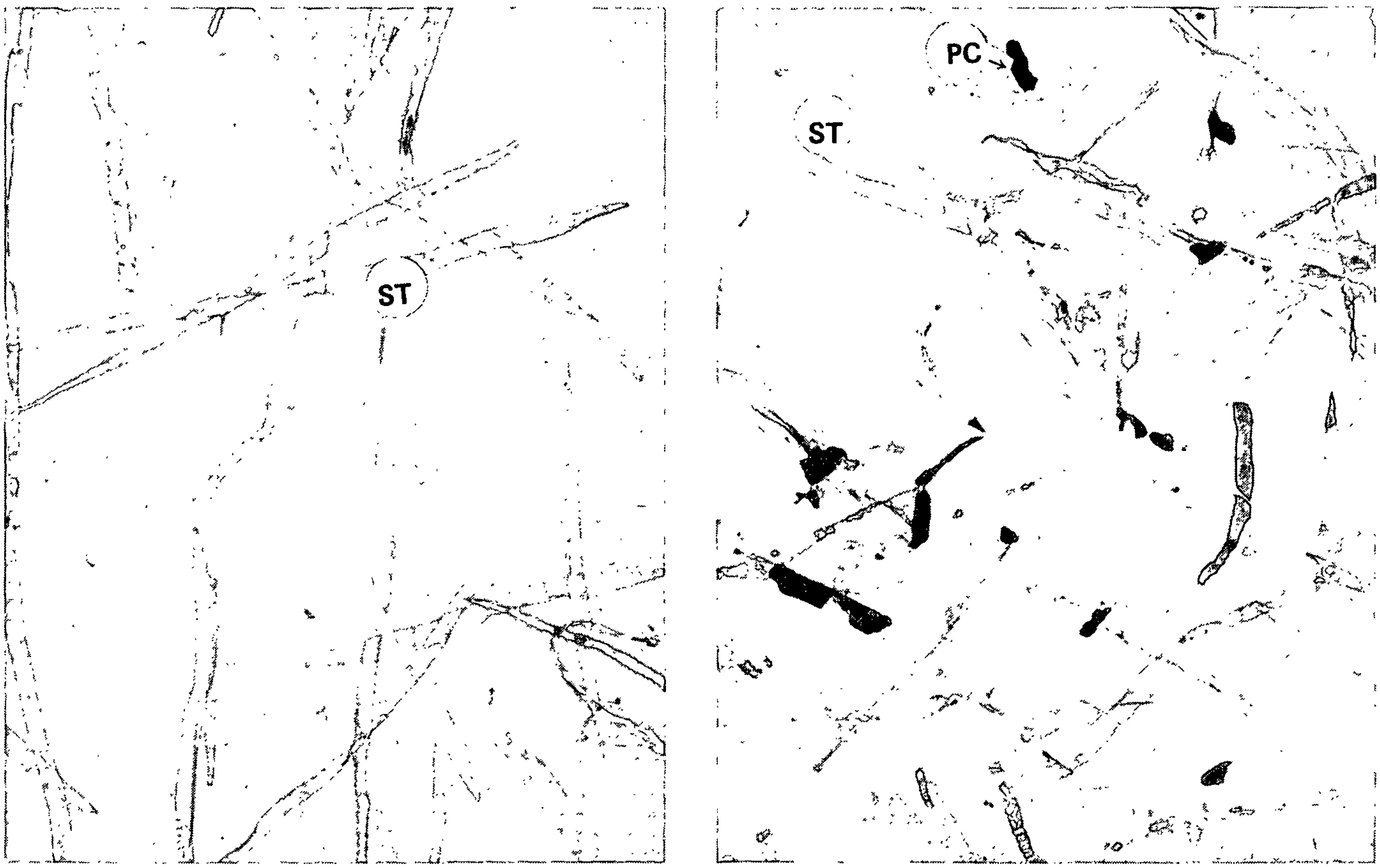


Figure 8. The 60-mesh Screen (Left) Contained by Weight Principally Sieve Tubes (100-%). The 150-mesh Screen (Right) Contained a Large Percentage of Sieve Tubes (60-70%) and Parenchymatous Cells (30-40%). Magnification — 75X. Symbols Illustrate Sieve Tubes (ST) and Parenchymatous Cells (PC)

The pulping of short-rotation red alder was reported in a paper by Schmidt and DeBell (27). They found that the presence of bark reduced initial freeness and increased fiber fines but had little effect on strength properties and sheet density.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study was to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for red alder samples collected January 15 and February 8 (dormant season). Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly formed xylem elements just outside the cambium zone.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 9 illustrates the zone of failure for red alder during the dormant season on one of the sections examined. As illustrated by this photomicrograph, failure occurred in the dormant cambium zone, primarily along the cambium cells located immediately adjacent to the last-formed cells in the xylem.

The failure zone of another Instron tested sample indicated that the break occurred in the secondary phloem in a fairly uniform tangential line between phloem parenchyma cells and sieve tubes located approximately 450 µm from the cambium zone. This is more typical of failure during the dormant season than the first sample. Figure 10 illustrates failure for this sample. Adhesion measurements averaged 10.2 kg/cm^2, an intermediate value compared to other hardwoods tested.

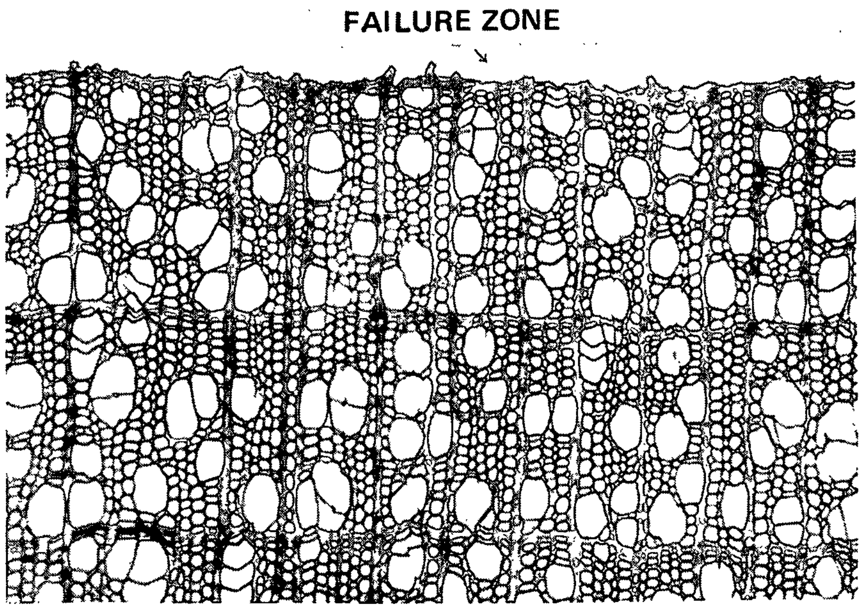


Figure 9. Illustrated is the Red Alder Failure Zone During the Dormant Season. Failure in This Sample Occurred in the Dormant Cambium Zone, Primarily Along the Cambium Cells Located Immediately Adjacent to the Last-formed Cells in the Xylem. Magnification — 75X

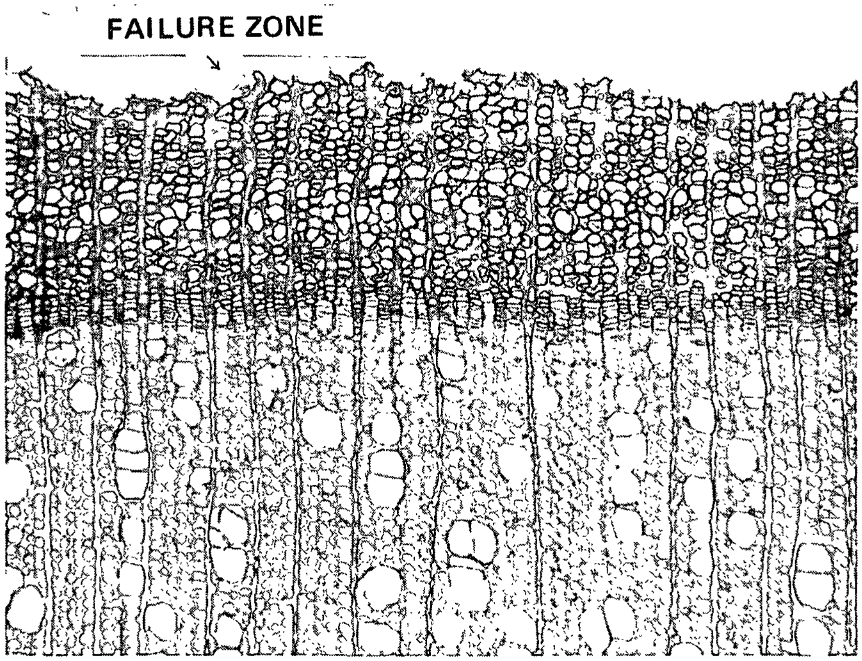


Figure 10. Illustrated is Another Zone of Failure for Red Alder During the Dormant Season. Failure Occurred in the Secondary Phloem in a Fairly Uniform Tangential Line Between Phloem Parenchyma Cells and Sieve Tubes Located Approximately 450 μm from the Cambium Zone. Magnification — 75X

As a result of measurement data taken on the species included in Appendix Table XXX and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. The lack of phloem fibers in red alder is probably a factor in the intermediate adhesion value. Low dormant season adhesion, noticed particularly in the conifers investigated, appears to be due primarily to the lack of fibers in the inner bark. High numbers of sclereids and/or a lack of phloem fibers also seems to be associated with low bark strength.

Hillstrom (28) attempted compression debarking with red alder with good results. More than 90% of the bark was removed with a wood loss of 8.5%. Pre-steaming was not necessary for this species and the adherence of bark to the compression rolls and fragmentation of the bark due to the nip action of the rolls followed by screening made it possible to obtain excellent bark removal.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table X summarizes the bark strength and toughness tests made on the wood and bark of red alder. (Appendix Tables XXXII and XXXIII compare the modulus of elasticity of red alder bark with other species examined in this project.)

TABLE X

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF RED ALDER[a]

Material	Strength	Toughness
Wood	--	0.50
Inner bark	8.2	0.10
Outer bark	5.9	0.02

[a]Determinations average of two trees, except outer bark strength which is based only on tree 3212-105.

Bark strength values for both inner and outer bark of red alder were intermediate compared to other hardwoods tested thus far. Toughness values for both the wood and the bark were fairly low. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the fairly high specific gravity of the bark and the intermediate strength and low toughness measurements, it appears that hammermilling would work fairly well on this species.

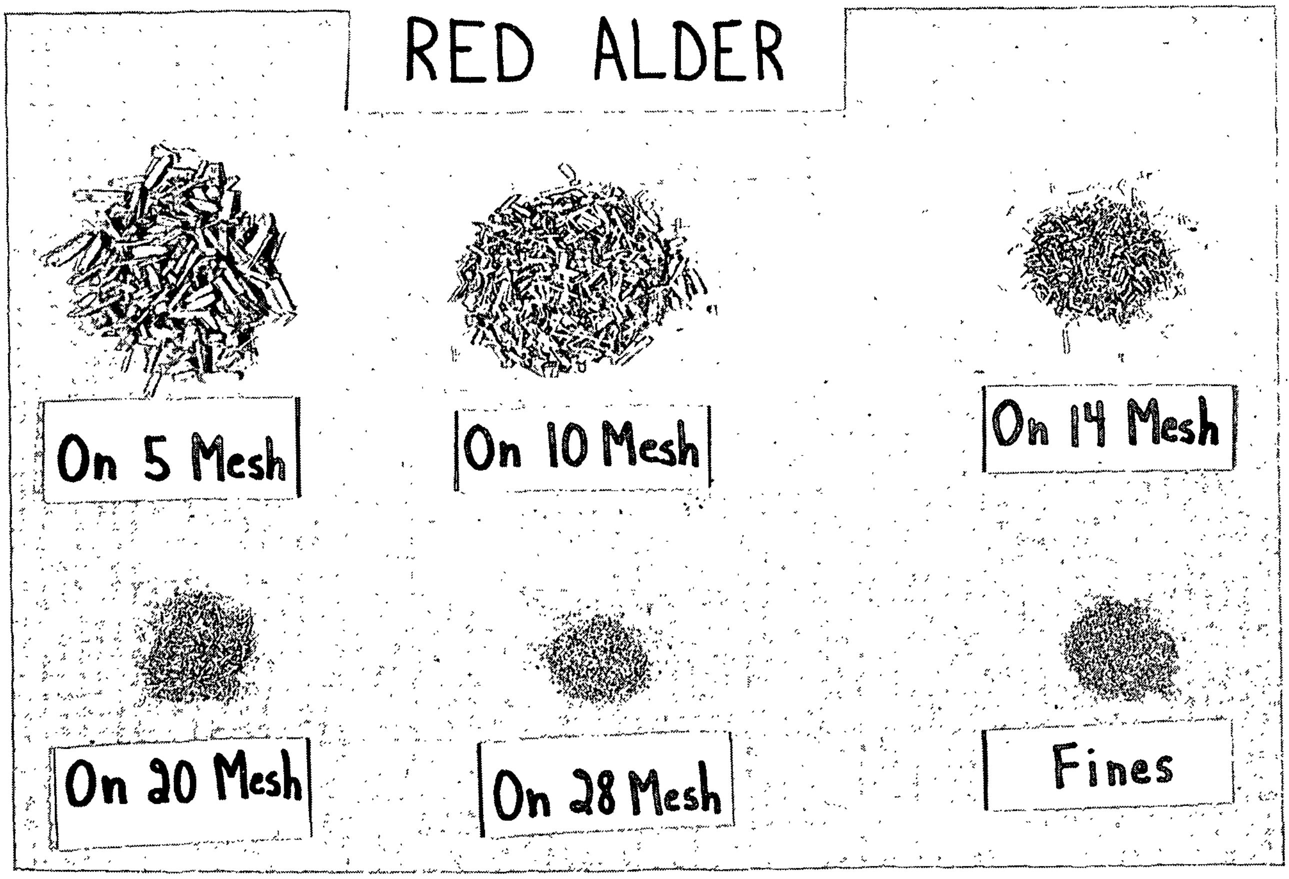
Summarized in Table XI are the results of the hammermilling tests run on red alder wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in a high reduction in levels of bark, as predicted by the bark strength and toughness measurements. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was an 8% wood loss and a 48% reduction in levels of bark. This is the highest reduction in bark levels obtained so far. An even larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be greatly increased (72% bark removal and 16% wood loss). Since red alder bark contains no fiber, there is no real benefit associated with pulping it. Consequently, there may be justification to an increased wood loss in view of the fuel value of the wood and the accompanying increased bark removal. Figure 11 illustrates the effect of hammermilling on wood and bark of red alder. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method, like compression debarking, for example. It is also possible improvements could be made in screening results by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 11 (14-16). This would require changes in screen design. Summary Table XXVIII compares bark strength, toughness and reaction to hammermilling of red alder with other species tested thus far.

TABLE XI

SUMMARY OF HAMMERMILLING TEST ON RED ALDER

Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-105	Bark	10.0	18.1	19.8	13.6	16.7	21.7	Outer bark stayed attached to inner bark. Outer bark very thin layer
	Exterior wood	58.0	27.2	6.8	3.0	2.2	2.8	
	Interior wood	50.2	31.3	8.3	3.8	2.9	3.5	
3212-108	Bark	5.9	21.7	27.4	13.0	12.9	19.1	Same as 3212-105
	Exterior wood	60.9	25.8	6.8	2.2	1.6	2.6	
	Interior wood	60.2	24.0	7.9	2.7	2.3	2.9	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.



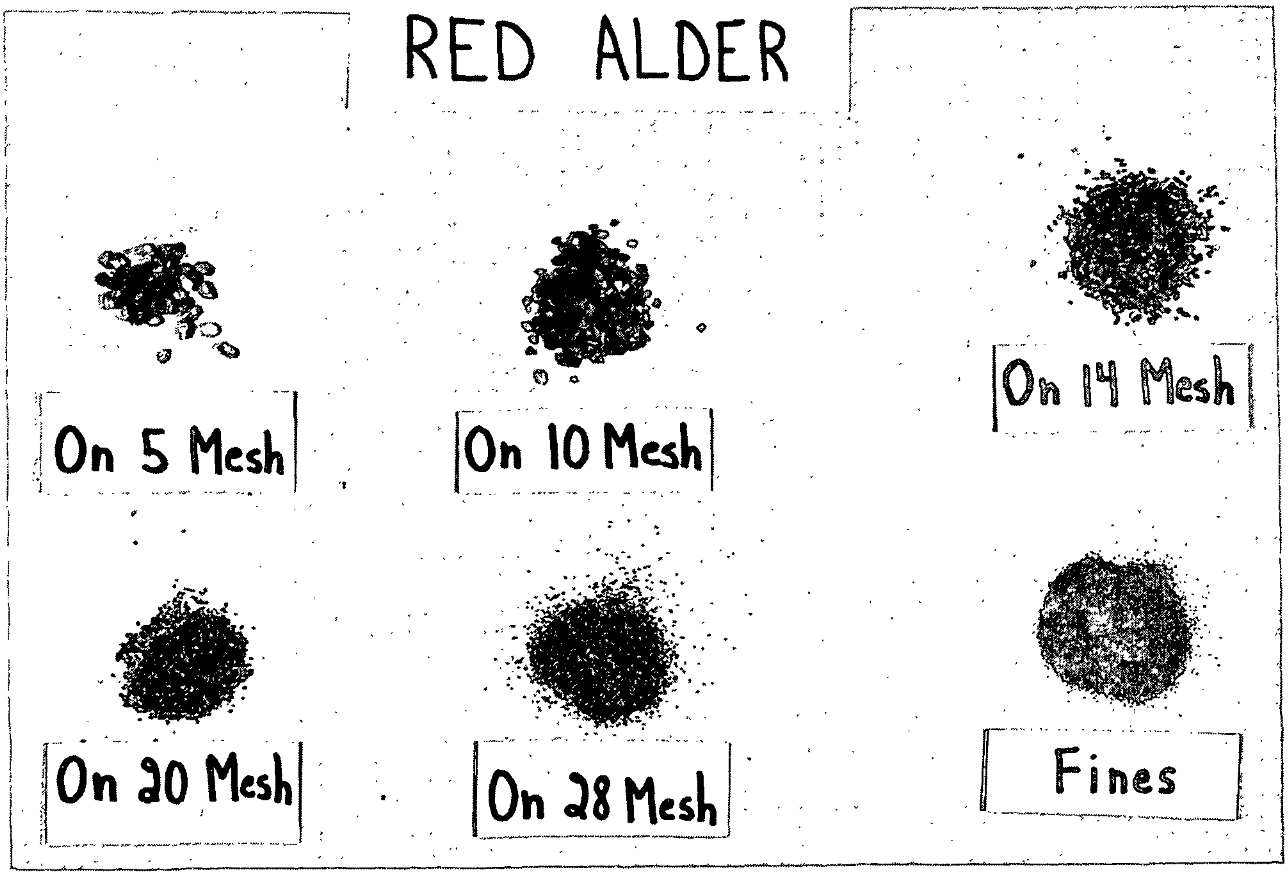


Figure 11. Illustrated is the Effect of Hammermilling on Red Alder Wood (Top) and Bark (Bottom)

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two red alder trees (IPC 3212-105 and IPC 3212-108) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner bark were also tested. The inner bark was very close to total bark in density at the various moisture contents.

Figure 12 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation is possible for red alder wood and bark chips. At moisture contents of 60-70%, bark would begin to sink while the wood would still be floating. This is true for moisture contents up to about 160%. With such a wide range of moisture contents at which segregation is possible, the water flotation technique looks feasible for red alder. Robins (29) also found red alder a good candidate for the cartesian-diver process with segregation possible at 40 psig for 60 seconds, then 20 seconds for settling without pressure. Red alder was tested in a fresh, as-chipped state.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and

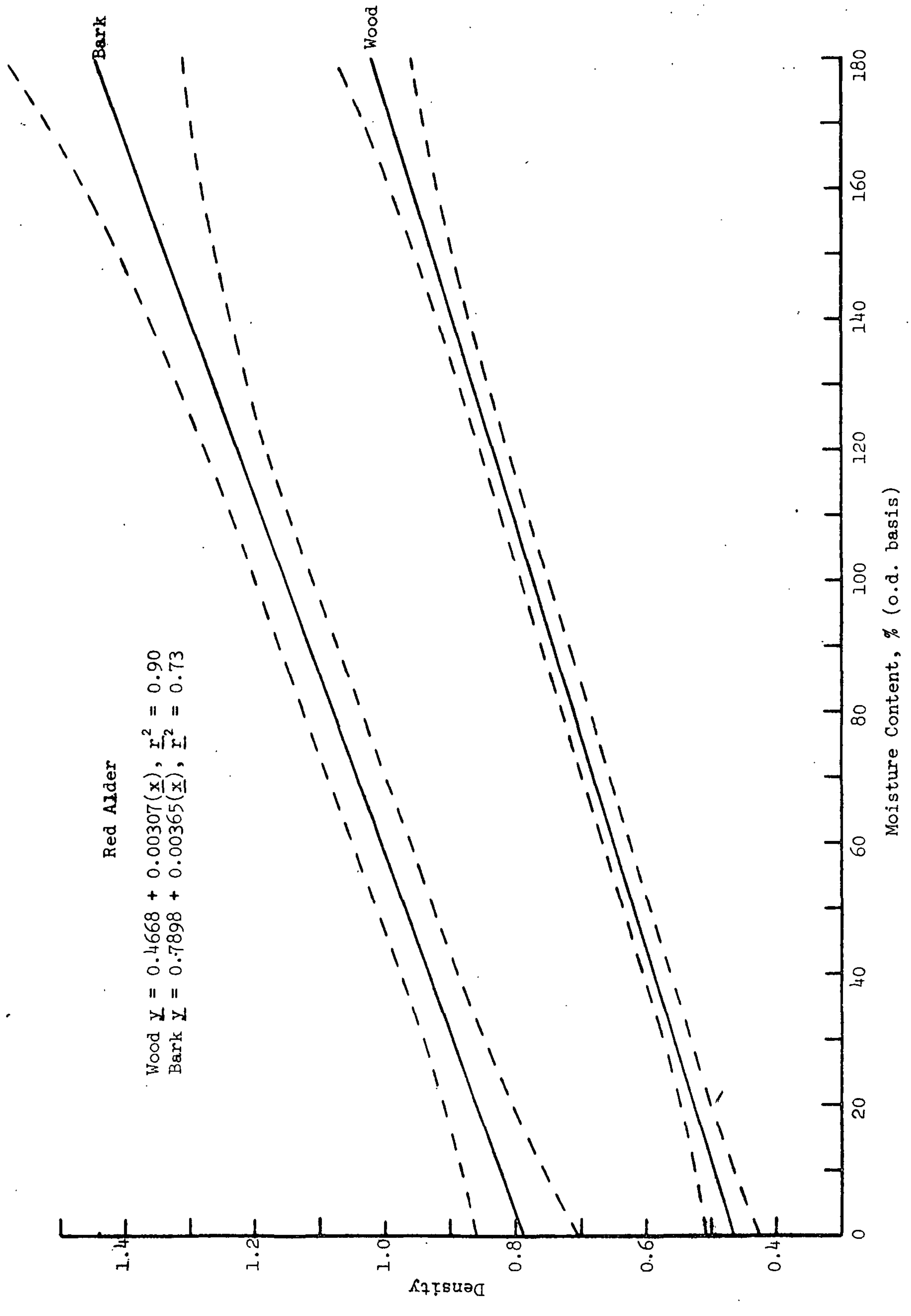


Figure 12. Illustrated is the Relationship Between Basic Density and Moisture Content for Red Alder. The Dashed Lines are Two Standard Deviations Above and Below the Mean

observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XII summarizes the results for red alder. These results agree with the results obtained in the density determination measurements which showed both wood and bark floating at 20% moisture content. The results also indicate that relatively dry wood and bark do not rapidly take up moisture and so could not be segregated unless treated in some special manner or the original starting moisture content is above 50%.

DATA INTERPRETATION

Unlike black spruce for which it is difficult to suggest a way to handle the bark, there are a number of ways in which red alder bark could be handled. Both mechanical means of separation and segregation and water flotation would work on this species. The simulated hammermilling test gave the highest bark removal of any species tested thus far, 48% bark removal and 8% wood loss by retaining the material on the 14-mesh or larger screens. Compression debarking is an equally promising technique with more than 90% of the bark removed. Segregation through water flotation is possible at moisture contents of 60-70% to 160%. At these

TABLE XII

SUMMARY OF DWELL TIME RESULTS FOR RED ALDER[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-105 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-105 Exterior wood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-105 Interior wood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-108 Bark	after 5	0	100
	15	0	100
	60	0	100
	240	0.7	99.3
IPC 3212-108 Exterior wood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100
IPC 3212-108 Interior wood	after 5	0	100
	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

moisture contents, the bark would sink while the wood would still be floating. In addition, the species could be segregated with northern black cottonwood which has similar densities at the same moisture contents. Even if a good share of the bark was pulped with the wood, the bark is low in extractives and most of the bark solids would be lost in washing and screening operations. Only 1.1% sieve tubes and 0.1% of other material would be retained on the 60- and 100-mesh screens. There is no fiber in the bark of red alder.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (17), Hooper (18), Biltonen, *et al.* (19), Short, *et al.* (20), Miller (21) and Vais and Vostrov (22). The previously cited paper by Smith and Kozak (25) also contains information on thickness and moisture content of red alder bark.

BARK AND WOOD PROPERTIES OF NORTHERN BLACK COTTONWOOD
(*Populus trichocarpa* Torr. and Gray)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Northern black cottonwood, largest of the American poplars, grows best in the humid climate of the Pacific Northwest where it is also the largest hardwood of the region. Its range extends from Kodiak Island and southeastern Alaska southward along the Pacific Coast to mountain areas in Baja California, Mexico and eastward in a triangular area throughout most of British Columbia to south-central Montana. Within the range, the climate varies from relatively arid to humid; and soils, from moist gravels and sands to rich humus and occasionally clay. In drier areas, this species is found usually on bottom land, along stream banks and pond edges, and at the foot of moist mountain slopes. According to studies made in British Columbia, black cottonwood requires abundant moisture, nutrients, and oxygen aeration and a soil pH of 6.0-7.0 for optimum growth. Maturity as well as diameter and height are greatly dependent on site quality. Trees reach 12-13 inches dbh and 45 ft. when 82 years old on Montana sites, and mature in 75 years in California with maximum diameters of 24 inches and heights of 60 feet. Exceptional growth has been found in the Fraser Valley of British Columbia where individuals have reached 32.5 inches dbh and 120 feet in 27 years and studies have shown the species to grow well up to 200 years of age.

WOOD AND BARK MORPHOLOGY

Wood

The wood of northern black cottonwood is medium textured and moderately light to light (sp. gr. approximately 0.32-0.37 green, 0.37-0.43 ovendry). The whitish sapwood frequently merges into the grayish white to light grayish brown heartwood. Inconspicuous growth rings are narrow to wide with numerous, small pores gradually decreasing in size through the latewood. The wood is semiring to diffuse porous. Parenchyma are terminal, appearing more or less distinct as a narrow light-colored line. Vessels number 30-145 per sq. mm, averaging 0.58 mm in length and are up to 75-150 µm in diameter. Thin to medium-thick-walled fibers average 1.38 mm in length and 23-40 µm in diameter (30). The fine rays, scarcely visible with a hand lens, are unstoried, uniseriate and essentially homogeneous.

Bark

The bark of northern black cottonwood is tawny yellow to gray and smooth on young stems. It later becomes dark gray to grayish brown and is separated by furrows into narrow flat-topped ridges. The total average thickness of the bark on one of the trees examined (3212-104) was 5.5 mm. The thickness of the inner bark was approximately 4.25 mm and the outer bark approximately 1.25 mm. The inner bark of trees 3212-109 and 3212-116 averaged 58.5% by weight. Figure 13 illustrates a cross section of inner and outer bark. Appendix Table XXIX describes the trees used in this study.

Anatomical Structure of Bark

The mature bark of *P. trichocarpa* is similar to that of *P. balsamifera* and *P. heterophylla* and differs from the bark structure of other species of *Populus* by the distinct formation of a rhytidome which is composed of alternate layers of secondary phloem and periderm in the outer bark.

The structure of the secondary phloem of black cottonwood is quite similar to the bark structure of other species of *Populus*. The inner bark is composed of thin-walled sieve tubes which may be solitary but are mostly in small groups of two to five together with companion cells and phloem parenchyma. These cells are

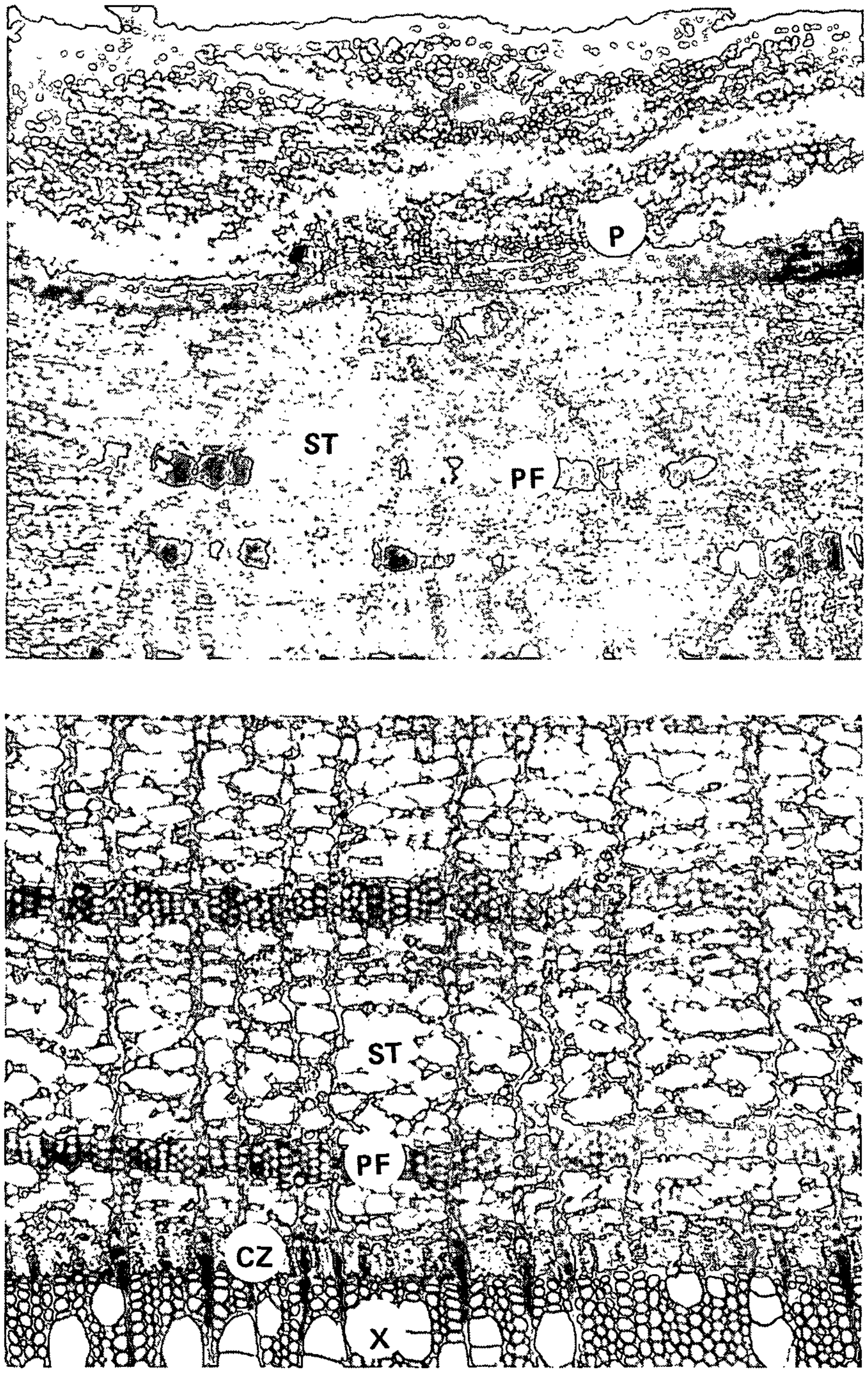


Figure 13. Cross Sections of Northern Black Cottonwood. Photograph on Bottom Shows Xylem (X), Cambium Zone (CZ), Sieve Tubes (ST), and Phloem Fibers (PF). Photograph on Top Shows Phloem Fibers (PF), Sieve Tubes (ST) and a Periderm Layer (P) of the Outer Bark. Magnification — 75X Bottom, 30X Top

bounded radially by uniseriate phloem rays which are essentially homogeneous and tangentially by bands of phloem sclerenchyma, composed principally of typical phloem fibers. The cross section of the fibers is polygonal and they are approximately 20-25 µm in diameter. The fiber cell walls are thick, about 10 µm and the lumen is narrow, approximately 2-3 µm. The average fiber length of the phloem fibers is approximately 1.0 mm. Figure 14 shows the calcium oxalate crystals also found in the secondary phloem of northern black cottonwood.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures.* Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIII summarizes the information available on wood and bark of northern black cottonwood. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that one of the values in the table is ovendry weight divided by ovendry volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of northern black cottonwood at several moisture contents.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

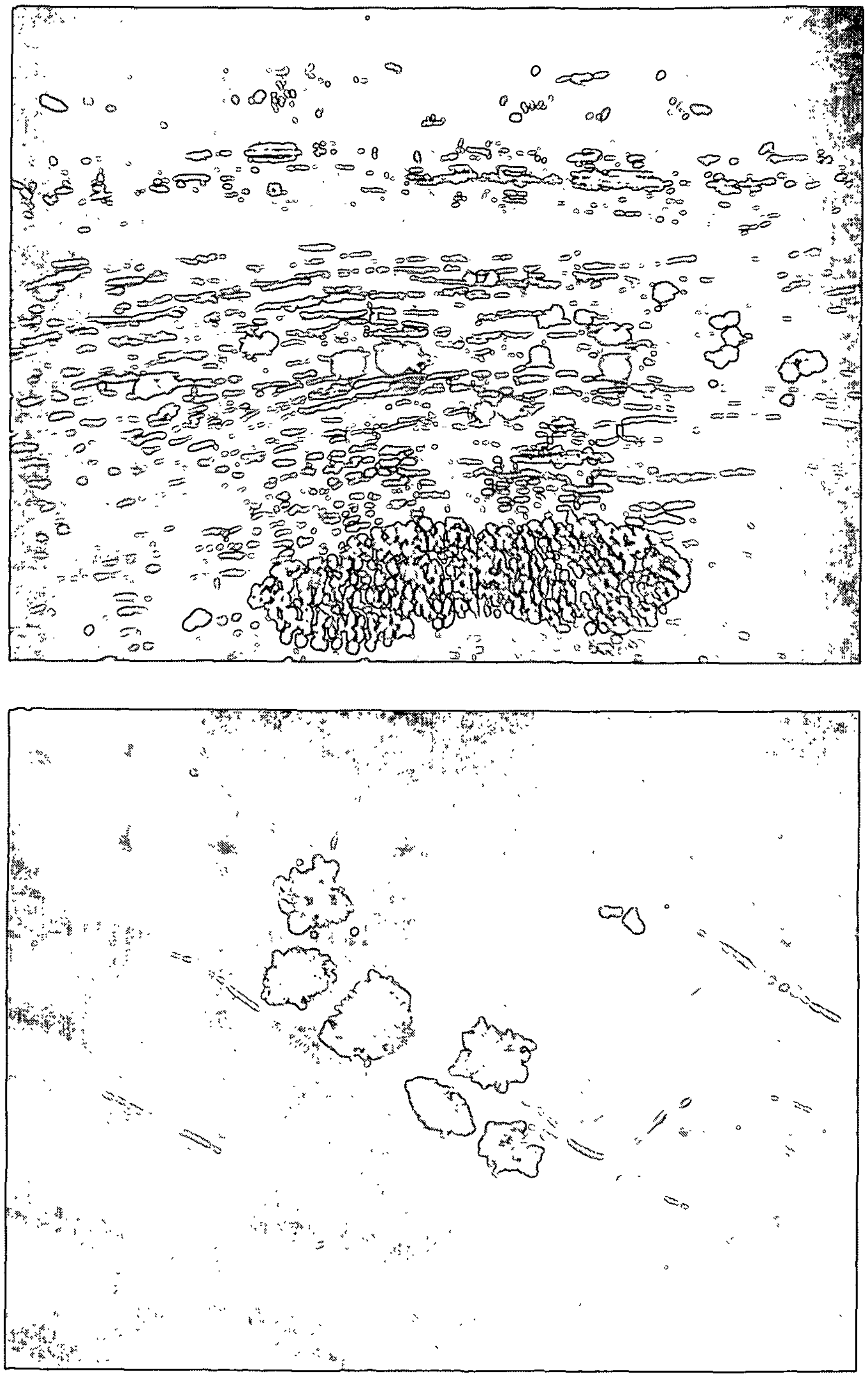


Figure 14. Partially Polarized Light Micrographs Illustrating the Occurrence of Calcium Oxalate Crystals in the Secondary Phloem of Northern Black Cottonwood. Magnification — 75X (Top) and 450X (Bottom)

TABLE XIII

NORTHERN BLACK COTTONWOOD SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Av.	Bark Inner	Bark Outer	Bark Total	References and Remarks
0.29				Irwin & Doyle (31)
0.32				Isenberg (6)
0.31				IUFRO (7)
0.31				USDA, For. Serv. (32)
0.32				Wood Handbook (33)
	0.41	0.44		Smith & Kozak (25)
0.22 (exterior wood) 0.26 (interior wood)	0.31	0.35	0.30	IPC 3212-104[a]
0.36 (exterior wood) 0.32 (interior wood)	0.40	0.58	0.51	IPC 3212-109
0.33 (exterior wood) 0.32 (interior wood)	0.39	0.33	0.39	IPC 3212-116
0.37[b]				Isenberg (6)

[a]Wood exhibited some stain.
[b]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.32 appears appropriate for the wood of northern black cottonwood. Our samples were divided into interior and exterior wood and specific gravity determinations made on each. For 3212-104 and 3212-116, the interior wood constituted the first 6 rings (approximately) out of a total 12+ rings and 13 rings, respectively. This is an approximate age for 3212-104 as growth rings were difficult to see due to stain in the wood. The first 22 rings out of a total 28 rings constituted the interior wood for 3212-109. Our limited data showed the interior wood and exterior wood to be fairly close in specific gravity.

The specific gravity of the total (inner + outer) bark of northern black cottonwood is somewhat higher than that of the wood. The outer bark was higher in specific gravity than the inner bark on two trees of the three trees examined in this project and was confirmed by one literature value. There was somewhat more variability than usual in the bark specific gravity values but overall average values suggested for use in species comparisons are 0.31 for wood and 0.38, 0.42 and 0.40 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

No information was found in the literature on alcohol-benzene extractives and the table includes only IPC information. Table XIV summarizes these measurements. Northern black cottonwood wood is low in extractives and a level of 2.3% is suggested for use in between-species comparisons. Extractives work done on northern black cottonwood bark in this project showed an average level of approximately 20.0%. This is a high level but should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques. The level of bark extractives given in Table XIV was quite variable but all values were checked in at least duplicate. Again, it is important to remember that the data in these reports are general trends, as there can be considerable variation within a species. Also, the condition of the bark, i.e., somewhat deteriorated in the case of 3212-104 and fresh and high in moisture in tree 3212-116, appears to have contributed to the variability in levels of extractives. Extractives content of air-dried bark has been reported to be less than that of fresh bark. Most IPC values reported in this project are based upon airdry samples.

TABLE XIV

NORTHERN BLACK COTTONWOOD ALCOHOL-BENZENE EXTRACTIVES

Type of Material[a]	Extractives, %	Sources
Wood	2.1	IPC 3212-104
Wood	2.0	IPC 3212-109
Wood	2.9	IPC 3212-116
Bark	10.4	IPC 3212-104
Bark	18.6	IPC 3212-109
Bark	32.8	IPC 3212-116

[a]Extractives run on airdry samples for tree 3212-104 and 3212-109 and on a fresh sample for tree 3212-116.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product. The principal element in the bark of northern black cottonwood having an effect on the pulp is phloem fibers.

The thin-walled sieve tubes (see photomicrographs) also found in northern black cottonwood bark could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem. However, the level of sieve tubes is quite low in the usable, pulped bark of northern black cottonwood.

Sclereids are short, thick, heavily lignified cells. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. However, sclereids are found in very low levels in the pulped bark of northern black cottonwood.

As a check on pulp yield and the nature of the material produced from northern black cottonwood, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XV summarizes the results of this investigation. A third tree was obtained and the bark pulped to supplement the usual two trees used as the bark from tree 3212-104 was somewhat deteriorated. Despite this, results from all trees were similar. Micropulping northern black cottonwood bark

TABLE XV

NORTHERN BLACK COTTONWOOD MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-104	3212-109	3212-116	Remarks[a]
Yield, % solids	24.1	26.9	27.0	
Fraction				
On 60 mesh, %	43.0	30.4	48.9	The fraction contained principally phloem fibers (100-%) with a trace of parenchymatous cells (<1%). Average arithmetic fiber length was 1.01 mm
On 100 mesh, %	6.4	5.5	5.7	The fraction contained principally phloem fibers (90-100%) with small percentages of sieve tubes (<5%) and parenchymatous cells (<5%)
On 150 mesh, %	2.3	1.4	1.7	The fraction contained sieve tubes (40-50%), parenchymatous cells (30-40%), phloem fibers (10-20%), sclereids (<5%) and a trace of crystalliferous parenchyma (<1%)
On 200 mesh, %	2.3	1.5	1.4	The fraction contained large percentages of parenchymatous and peridermal cells (50-60%), and sieve tubes (30-40%), with small percentages of sclereids (5-10%), phloem fibers (<5%) and crystalliferous parenchyma (<5%)
Through 200 mesh, %	46.0	61.2	42.3	The fraction contained principally parenchymatous and peridermal cells (70-80%) with small percentages of crystalliferous parenchyma (10-20%), sieve tubes (5-10%) and sclereids (<5%)

[a]Percentages given are on a dry weight basis.

resulted in a yield of 24 to 27% solids. When screened, the coarse screens (60 and 100-mesh) retained mostly phloem fibers. The on 150-mesh screen contained a large percentage of sieve tubes plus some parenchymatous cells and phloem fibers. The on 200-mesh screen and through 200-mesh screen contained large percentages of parenchymatous and peridermal cells with smaller amounts of sieve tubes, crystalliferous parenchyma and sclereids. Figure 15 illustrates the type of material on the 60- and 150-mesh screens.

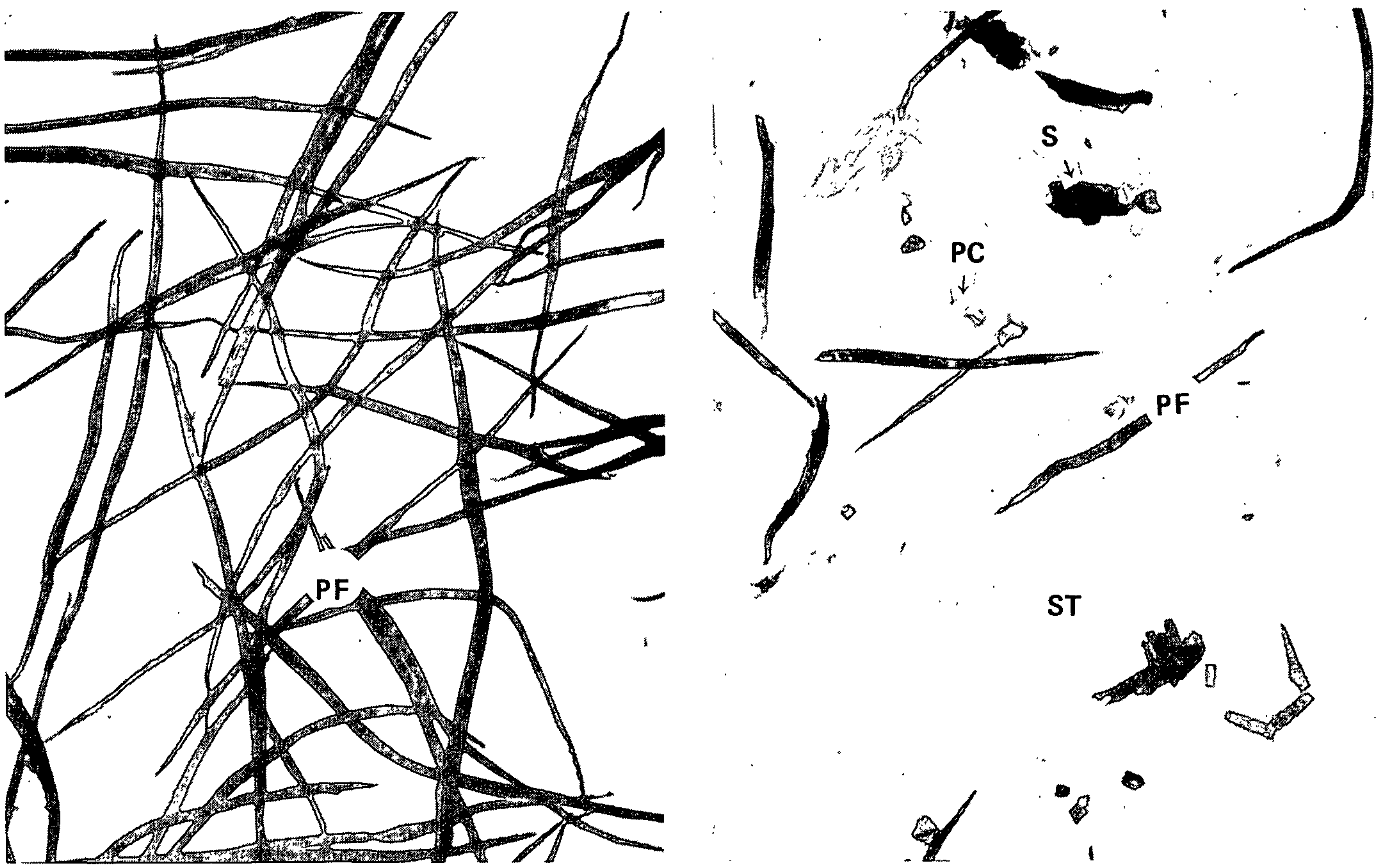


Figure 15. The 60-Mesh Screen (Left) Contained by Weight Principally Phloem Fibers (100-%). The 150-Mesh Screen (Right) Contained Sieve Tubes (40-50%), Parenchymatous Cells (30-40%), Phloem Fibers (10-20%) and Sclereids (<5%). Magnification — 75X. Symbols Illustrate Phloem Fibers (PF), Sieve Tubes (ST), Parenchymatous Cells (PC) and Sclereids (S)

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 26 grams of solids will result. Of this 26 grams, about 12 grams (12%) of phloem fibers and 0.1 gram (0.1%) of sieve tubes will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study was to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for northern black cottonwood samples collected January 15 and February 22 (dormant season). Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly formed xylem elements just outside the cambium zone.

Using the sampling and testing procedures described in the section on Experimental Procedure in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 16 illustrates the zone of failure for northern black cottonwood during the dormant season. Failure occurred in the secondary phloem in a jagged tangential line between sieve tubes, phloem parenchyma and phloem fibers located 0.2-0.5 mm from the cambium zone. Adhesion measurements averaged 18.7 kg/cm^2, a rather high value. These results were somewhat higher than those obtained for eastern cottonwood (13.5 kg/cm^2). However, failure zones were similar.

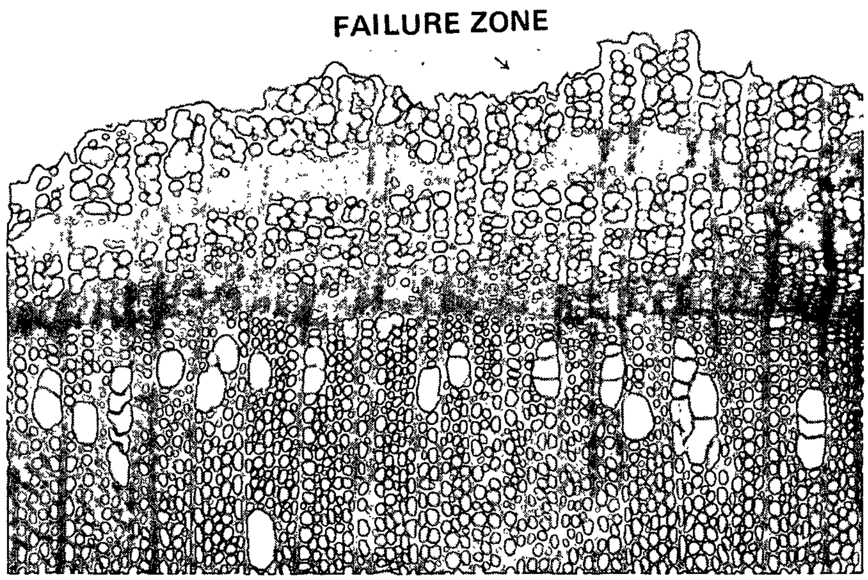


Figure 16. Illustrated is the Northern Black Cottonwood Zone of Failure on February 22. Failure Occurred in the Secondary Phloem in a Jagged Tangential Line Between Sieve Tubes, Phloem Parenchyma and Phloem Fibers Located 0.2-0.5 mm from the Cambium Zone. Magnification — 75X

As a result of measurement data taken on the species included in Appendix Table XXX and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology.

The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with northern black cottonwood. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One) bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XVI summarizes the bark strength and toughness tests made on the wood and bark of northern black cottonwood. (Appendix Tables XXXII and XXXIII compare the modulus of elasticity of northern black cottonwood bark with other species examined in this project.)

TABLE XVI

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS MADE ON WOOD AND BARK OF NORTHERN BLACK COTTONWOOD[a]

Material	Strength	Toughness
Wood	--	0.30
Inner bark	13.9	0.10
Outer bark	7.3	0.07

[a]Determinations average of two trees.

Bark strength values for northern black cottonwood inner bark were high compared to other hardwoods tested thus far. Outer bark values were also high. Toughness values for both wood and bark were fairly low compared to other hardwoods tested. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the somewhat low specific gravity of the bark and high strength measurements, it appears that hammermilling might not work well on this species. However, this prediction is somewhat tentative because the results of the tests did not fall into a clear-cut pattern. Coupled with low bark specific gravity and high strength, which would give poor bark removal, was a low bark toughness which might make the results different than expected.

Summarized in Table XVII are the results of the hammermilling tests run on northern black cottonwood wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in a rather low reduction in levels of bark. This was based only on trees 3212-109 and 3212-116,

TABLE XVII

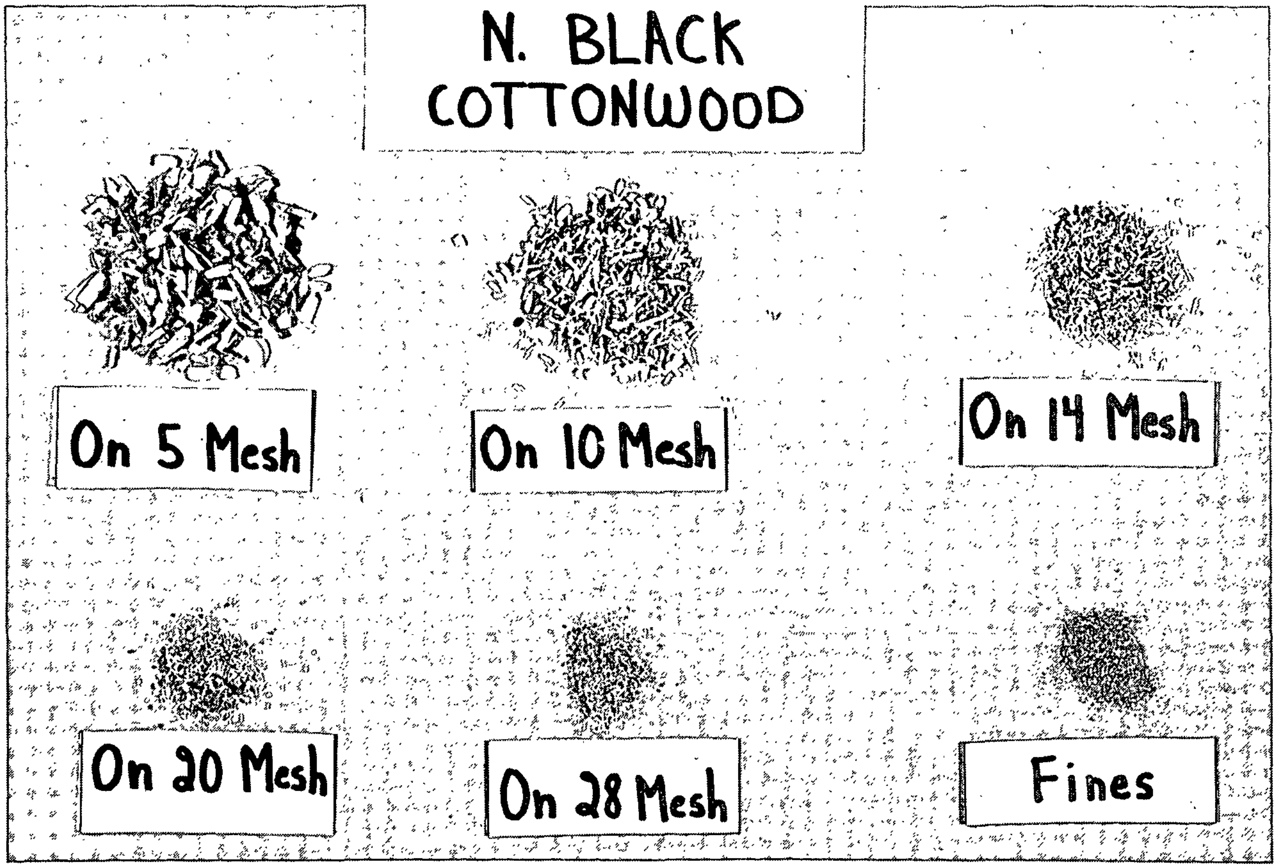
SUMMARY OF HAMMERMILLING TEST ON NORTHERN BLACK COTTONWOOD

		Fraction Retained on Standard Screen[a], %						
Tree No.	Material	5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-104	Bark	14.6	22.3	14.5	7.8	8.2	32.5	Outer bark rounder-shaped pieces; inner bark long and stringy. Two-thirds inner bark on larger mesh screens; more outer bark on smaller mesh screens
	Exterior wood	52.1	29.3	9.3	3.4	2.8	3.0	
	Interior wood	55.1	28.5	8.0	3.0	2.4	2.9	
3212-109	Bark	36.4	27.0	9.8	4.1	6.1	16.6	Same as 3212-104
	Exterior wood	72.4	16.6	5.2	2.0	1.8	2.0	
	Interior wood	61.6	26.0	6.2	2.2	1.8	2.2	
3212-116	Bark	43.8	21.6	9.9	5.2	5.0	14.5	Same as 3212-104
	Exterior wood	65.2	24.3	6.0	1.9	1.1	1.5	
	Interior wood	67.8	21.5	6.6	1.7	1.1	1.3	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

as the bark of 3212-104 was in a somewhat deteriorated condition and more of it ended up on the smaller-mesh screens. The result obtained with tree 3212-104, in which there was a slight amount of bark deterioration and a much greater reduction in bark levels as the result of hammermilling, suggest this approach, i.e., deliberate deterioration of bark prior to mechanical treatment, should be investigated further.

When the half-sized chips for the two trees (3212-109 and 3212-116) were hammermilled and the material on the 14-mesh screen retained, the result was a 5% wood loss and a 26% reduction in levels of bark. This is an intermediate reduction in bark compared to many of the other hardwoods investigated thus far. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be greatly increased (36% bark removal and 11% wood loss). Since cottonwood bark is high in fiber, the increased wood loss may not justify the additional bark removal. Figure 17 illustrates the effect of hammermilling on wood and bark of northern black cottonwood. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible improvements could be made in screening results by taking advantage of the differences in configuration of wood and bark chips evident in Fig. 17 (14-16). This would apply to outer bark only, which is in rounder pieces after hammermilling, rather than inner bark which, due to the fiber it contains, is long and stringy. Summary Table XXVIII compares bark strength, toughness and reaction to hammermilling of northern black cottonwood with other species tested thus far.



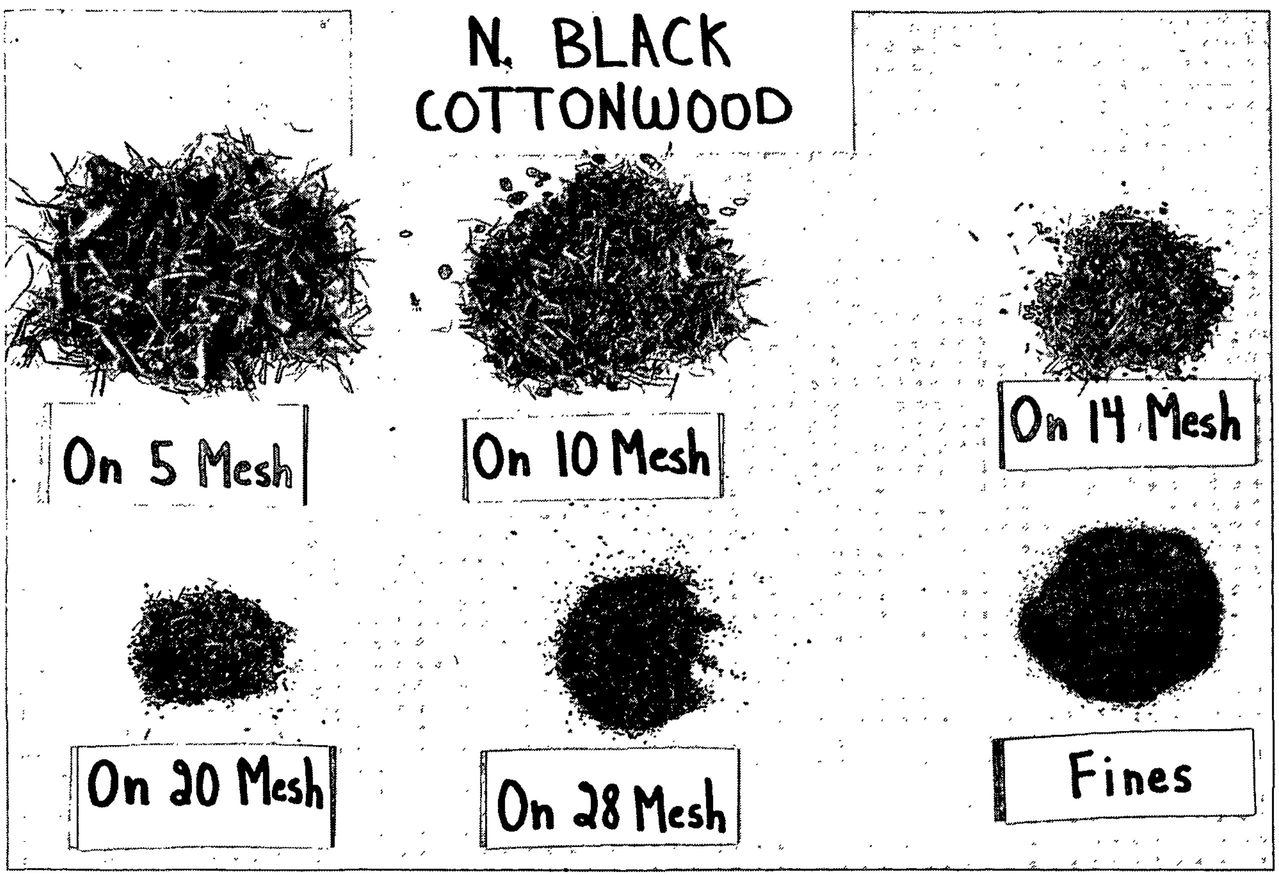


Figure 17. Illustrated is the Effect of Hammermilling on Northern Black Cottonwood (Top) and Bark (Bottom)

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two northern black cottonwood trees (IPC 3212-104 and IPC 3212-109) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determing density. Bark samples used were "whole bark" samples, a

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Inner, outer and total bark were all very close in density at the various moisture contents.

Figure 18 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation is possible for northern black cottonwood wood and bark chips. At moisture contents of 60%, bark would begin to sink while the wood would still be floating. This is true even at 180% moisture content. With such a wide range of moisture contents at which segregation is possible, the water flotation technique looks feasible for northern black cottonwood. Bark and wood chips from mixtures of northern black cottonwood and red alder could be segregated through water flotation as both species behave in a similar manner with bark sinking and wood floating at moisture contents of 60-70% or above.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and

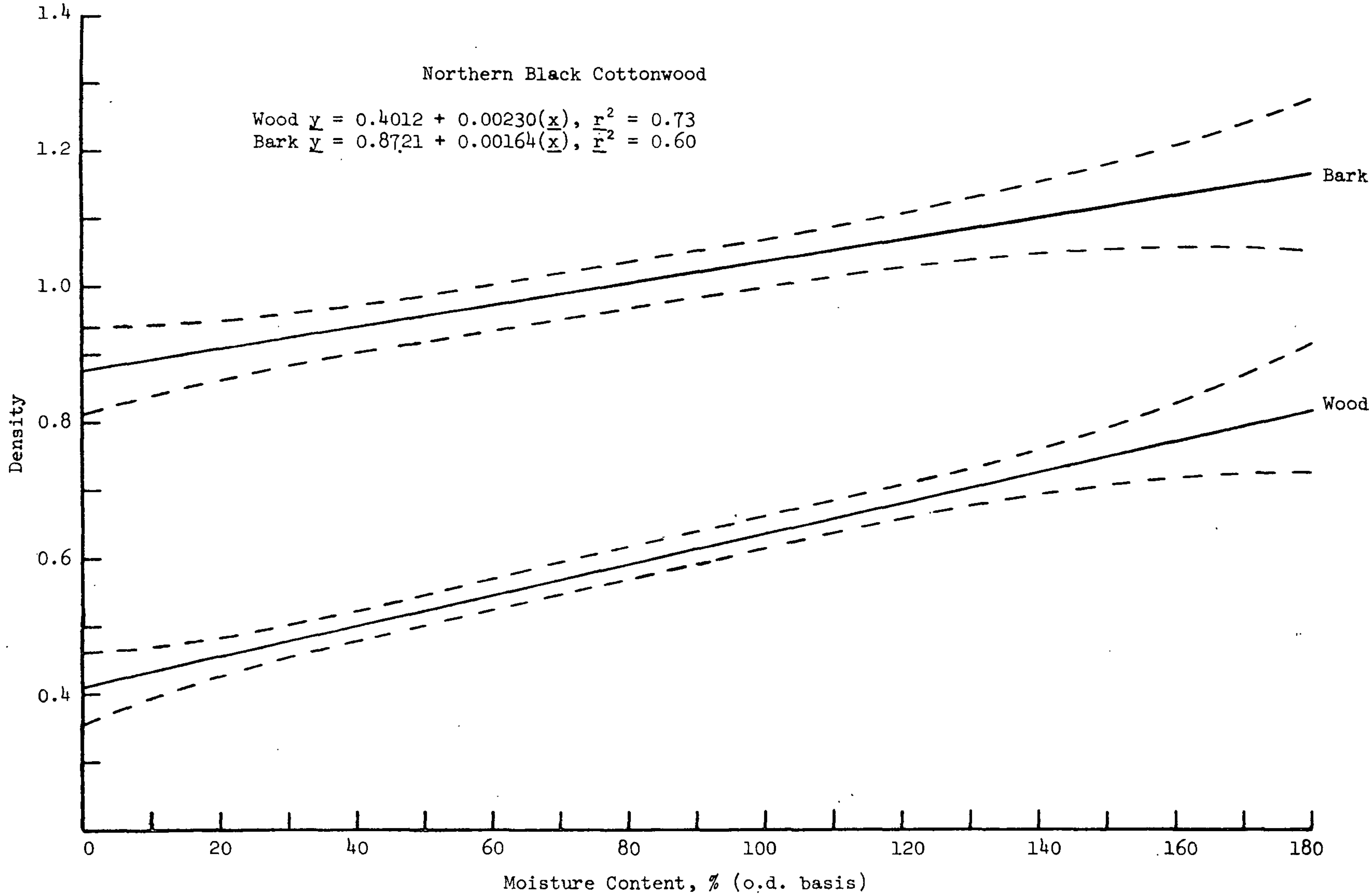


Figure 18. Illustrated is the Relationship Between Basic Density and Moisture Content for Northern Black Cottonwood. The Dashed Lines are Two Standard Deviations Above and Below the Mean

observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XVIII summarizes the results for northern black cottonwood. These results agree with the results obtained in the density determination measurements which showed both wood and bark floating at 20% moisture content. However, a small amount of bark did sink after four hours for 3212-109, probably indicating that, by that time, it had picked up enough moisture to bring it up to 60-70% moisture. Detached inner and outer bark would probably behave in a similar manner. Relatively dry wood and bark do not rapidly take up moisture and so could not quickly be segregated unless treated in some special manner or the original starting moisture content is above 50%.

DATA INTERPRETATION

Fiber yield from the bark of northern black cottonwood is high and the level of sclereids is very low. Pulping northern black cottonwood bark resulted in 12% phloem fibers and 0.1% sieve tubes being produced, assuming that only the material on the 60- and 100-mesh screens would be retained. However, since northern black cottonwood is high in extractives, it may be desirable to remove

TABLE XVIII

SUMMARY OF DWELL TIME RESULTS FOR NORTHERN BLACK COTTONWOOD[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-104	after 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-104	after 5	0	100
Exterior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-104	after 5	0	100
Interior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-109	after 5	0	100
Bark	15	0	100
	60	0	100
	240	4.4	95.6
IPC 3212-109	after 5	0	100
Exterior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-109	after 5	0	100
Interior wood	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

at least part of the bark. The mechanical treatment investigated in this project to separate and segregate wood and bark, hammermilling, gave intermediate results with a 26% reduction in levels of bark and a 5% wood loss by retaining the material on the 14-mesh or larger screens. Most of the bark removed was outer bark. Segregation through water flotation proved to be a feasible technique with segregation possible at moisture contents of 60-70% or above. At these moisture contents, the wood would float while the bark would sink. In addition, the species could be segregated with red alder which has similar densities at the same moisture content. Northern black cottonwood appears to be a species that could be handled with some success by first screening whole-tree chips to concentrate most of the bark in the small chip fraction (<3/8 inch), next mechanically treating (shredding or hammermilling) and rescreening that fraction to remove a modest amount of bark and reduce the grit and extractives problem and then pulping the remaining stringy, fiber-rich bark.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (17), Hooper (18), Biltonen, *et al*. (19), Short, *et al*. (20), Miller (21) and Vais and Vostrov (22). The previously cited paper by Smith and Kozak (25) also contains information on thickness and moisture content of northern black cottonwood bark.

WOOD AND BARK PROPERTIES OF SILVER MAPLE
(*Acer saccharinum* L.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Silver maple, found throughout Eastern United States, is most common and reachest its best development in the southern Ohio River Valley. The range extends from southeastern Canada westward to the borders of the Prairie States where it grows along streams providing ample moisture. Only in the coastal areas or the higher, colder elevations of the Appalachians is this species sparsely represented or entirely absent. Limited more by available moisture than soil texture, silver maple is most common where there is a good moisture supply throughout the growing season. Growth is most rapid during the first 50 years when it may grow 1/2 inch in diameter a year under good conditions. Mature trees generally reach heights of 75-120 feet and diameters of 2-4 feet although occasional trees may have diameters of 5 feet and more.

WOOD AND BARK MORPHOLOGY

Wood

Silver maple wood is generally straight-grained and moderately heavy (sp. gr. 0.44-0.49 green, 0.51-0.55 ovendry) with a wide white sapwood and light-brown heartwood. Growth rings, delineated by a narrow, darker line of denser fibrous tissue, are not very distinct. Small indistinct pores are distributed throughout the growth ring. On the tangential surface, rays are visible as short crowded lines. The wood of this soft maple is composed primarily of vessels, fibers and rays. Numbering 30-80 per sq. mm, silver maple vessels, with spiral thickenings, may have diameters up to 60-80 µm. The average vessel segment length is 0.41 mm. Parenchyma are sparse. The fibers are thin to moderately thick-walled, 16-30 µm in diameter, and average 0.76 mm in length. Rays are unstoried, 1-5 seriate and generally homogeneous.

Bark

The bark on young trees is silvery gray and later breaks up into long, thin scaly plates which are unattached at the ends. The total average thickness of the bark on one submitted sample of silver maple was approximately 3 mm and was principally inner bark with a narrow cortical region zone and a layer of periderm with an average thickness of 0.1-0.2 mm. The percent outer bark by weight ranged from 13-48%. The samples with a thicker outer bark were only scattered areas and the average percent outer bark of more representative samples was 19.5%. Figure 19 illustrates a cross section of inner and outer bark. Appendix Table XXIX describes the trees used in this study.

Anatomical Structure of Bark

The outer bark of the submitted specimen was limited to a periderm layer composed of 2-4 layers of phelloderm, a layer of phellogen and several layers of phellem cells. There was a lack of rhytidome formation in this particular specimen. However, thin, smooth bark appears to be fairly typical of pulpwood-sized trees and the tops of larger trees.

The cortical region occupies a proportionally narrow zone of the whole bark and is composed principally of cortex cells and some expanded secondary phloem tissues. The cortical zone does not show distinct demarcation from the secondary phloem. These two parts are merged together by cortical parenchyma, the dilated phloem rays, phloem parenchyma and scattered groups of sclerenchyma.

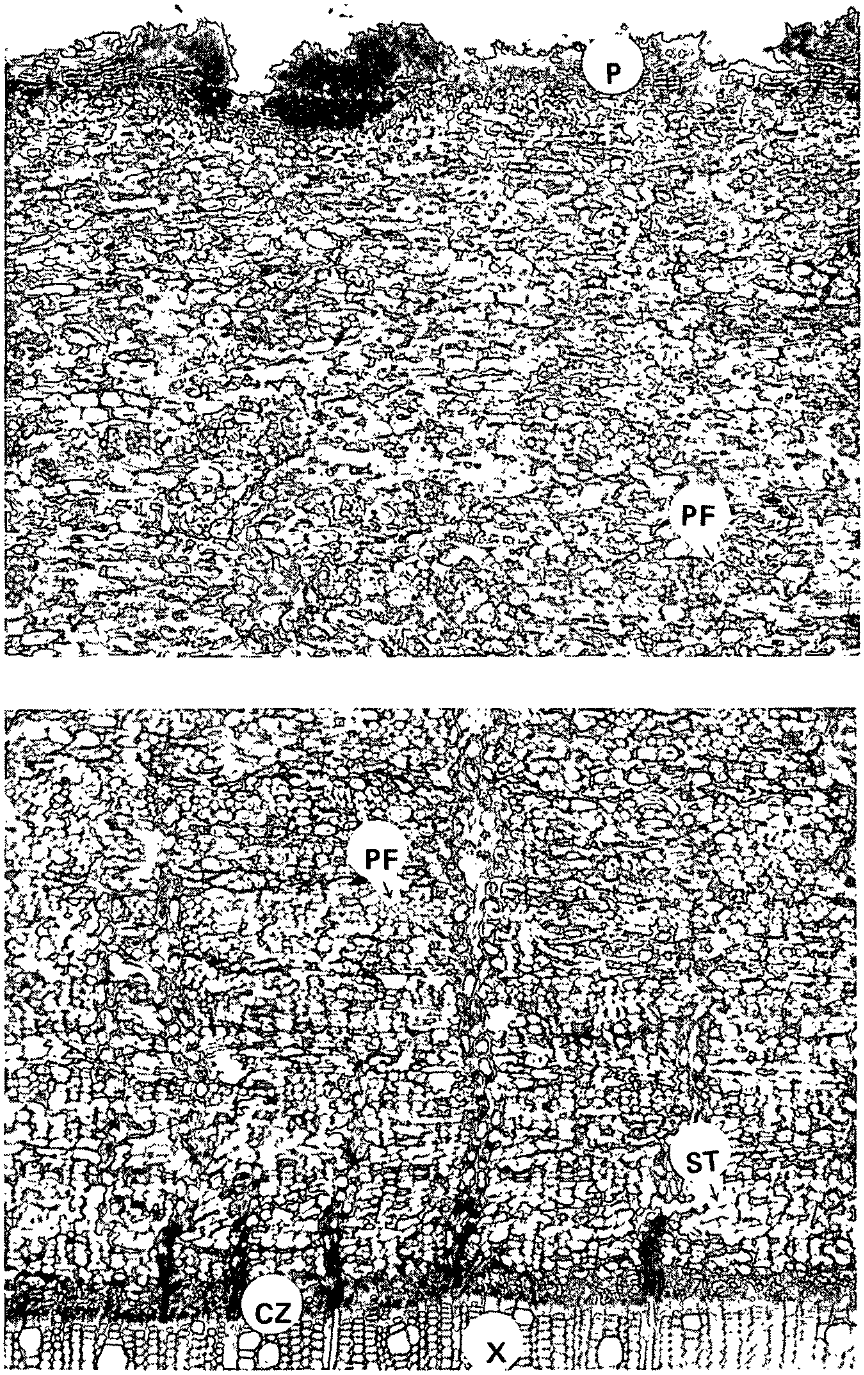


Figure 19. Cross Sections of Silver Maple. Photograph on Bottom Shows Xylem (X), Cambium Zone (CZ), Sieve Tubes (ST), and Phloem Fibers (PF). Photomicrograph on Top Shows Phloem Fiber (PF) and a Periderm Layer (P). Magnification — 75X

The secondary phloem is composed of alternate bands of sieve tubes, phloem parenchyma and sclerenchyma cells. These cells are bounded radially by rays which are 2-4 seriate and essentially homogeneous. Some of the rays have become "sclerified" and have merged into sclereid groups. Only the sieve tube groups in the proximity of the cambium zone have retained their fully developed shape and size. The remaining zones of sieve tubes have become more or less crushed.

The sclerenchyma in silver maple consists of sclereids and fibers. The sclereids are narrow, branched, fiberlike cells which appear at the middle portion of the inner bark with the more or less tangential bands of phloem fibers. The cambium zone is generally separated by 3-4 rows of sieve tubes and parenchyma cells from the last formed narrow (1-2 cells wide) tangential band of phloem fibers.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures.* Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIX summarizes the information available on wood and bark of silver maple. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in the table are ovendry weights divided by ovendry volumes. Information expressed in terms of

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of silver maple at several moisture contents.

TABLE XIX

SILVER MAPLE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Av.	Bark Inner	Bark Outer	Bark Total	References and Remarks
0.44				IUFRO (7)
0.44				Isenberg (6)
0.46 (increment core)				Maeglin (4)
0.43 (exterior wood) 0.39 (interior wood)	0.53	0.61	0.56	IPC 3212-11
0.40 (exterior wood) 0.39 (interior wood)	0.49	0.61	0.58	IPC 3212-12
0.50[a]				Isenberg (6)
			0.67[a]	Harkin & Rowe (26)

[a]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.42 appears appropriate for the wood of silver maple. Our samples were divided into interior and exterior wood and specific gravity determinations done on each. For 3212-11, the interior wood constituted the first 12 rings out of a total 24 rings and the first 20 rings out of a total 31 rings for 3212-12. Our limited data show the exterior wood to be slightly higher than the interior wood in specific gravity.

The specific gravity of the total (inner + outer) bark of silver maple is higher than that of the wood. The outer bark was higher in specific gravity than the inner bark on the two trees examined in this project. As stated in the previous section, there were certain scattered areas in the bark with thicker outer bark. Specific gravity determinations for outer bark were done on these areas as the outer bark was too thin elsewhere to run specific gravity determinations on it. Overall values suggested for use in species comparisons are 0.42 for wood and 0.51, 0.61 and 0.57 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

No information was found in the literature on alcohol-benzene extractives and the table includes only IPC information. Table XX summarizes these measurements. Silver maple wood is low in extractives and a level of 3.5% is suggested for use in between-species comparisons. Extractives work done on silver maple bark in this project showed an average level of 6.6% (air-dried samples). This is a low level and indications are that extractives are not expected to be a serious problem when pulping the bark of this species.

TABLE XX

SILVER MAPLE ALCOHOL-BENZENE EXTRACTIVES

Type of Material[a]	Extractives, %	Source
Wood	4.0	IPC 3212-11
Wood	3.0	IPC 3212-12
Bark	5.5	IPC 3212-11
Bark	7.6	IPC 3212-12

[a]Extractives were run on airdry samples for IPC determinations.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped silver maple bark.

The thin-walled sieve tubes (see photomicrographs) also found in silver maple bark could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of the problem. However, the level of sieve tubes is quite low in the usable, pulped bark of silver maple.

Sclereids are short, thick, heavily lignified cells in many species of trees. When not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fisheyes" in certain grades (calendered) of paper. However, silver maple sclereids are branched and tend to separate fairly easily. As such, they should not cause problems in paper. Branched sclereids of this type are different than the branched sclereids in balsam fir, for example. Balsam fir sclereids tend to remain in clumps and are found this way in cross sections whereas silver maple sclereids tend to be separated, even in the cross sections.

As a check on pulp yield and the nature of the material produced from silver maple, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XXI summarizes the results of this investigation. Micropulping silver maple bark resulted in a yield of 30 to 34% solids. When screened, the coarse screens (60 and 100 mesh) retained most of the phloem fibers and some of the sclereids. The on 150-mesh screen contained principally sclereids with some sieve tubes, phloem fibers and parenchymatous cells. The on 200-mesh and through 200-mesh screens contained large percentages of sclereids with smaller percentages of parenchymatous cells and sieve tubes. Figure 20 illustrates the type of material on the 60- and 150-mesh screens.

TABLE XXI

SILVER MAPLE MICROPULPING INVESTIGATIONS

Data[a]	Sample No. 3212-11	Sample No. 3212-12	Remarks[a]
Yield, % solids	34.3	30.0	
Fraction			
On 60 mesh, %	17.6	5.8	The fraction contained principally phloem fibers (95+%) with a small percentage of branched sclereids (<5%) and a trace of sieve tubes (<1%). The thick-walled fibers had an average width of 15 µm and an average length of 0.93 mm
On 100 mesh, %	18.8	13.8	The fraction contained phloem fibers (40-50%), sclereids (40-50%) and a small percentage of sieve tubes (10-20%). The average arithmetic length of sieve tubes was 0.51 mm
On 150 mesh, %	14.6	15.0	The fraction contained principally sclereids (60-70%), smaller percentages of sieve tubes (10-20%), phloem fibers (5-10%) and parenchymatous cells (5-10%)
On 200 mesh, %	9.6	13.4	The fraction consisted of a large percentage of sclereids (70-80%) with smaller percentages of sieve tubes (10-20%), phloem fibers (5-10%) and parenchymatous cells (5-10%)
Through 200 mesh, %	39.4	52.0	The fraction contained a large percentage of sclereids (55-65%), with smaller percentages of parenchymatous cells (35-45%) and sieve tubes (<1%)

[a]Percentages given are on a dry weight basis.

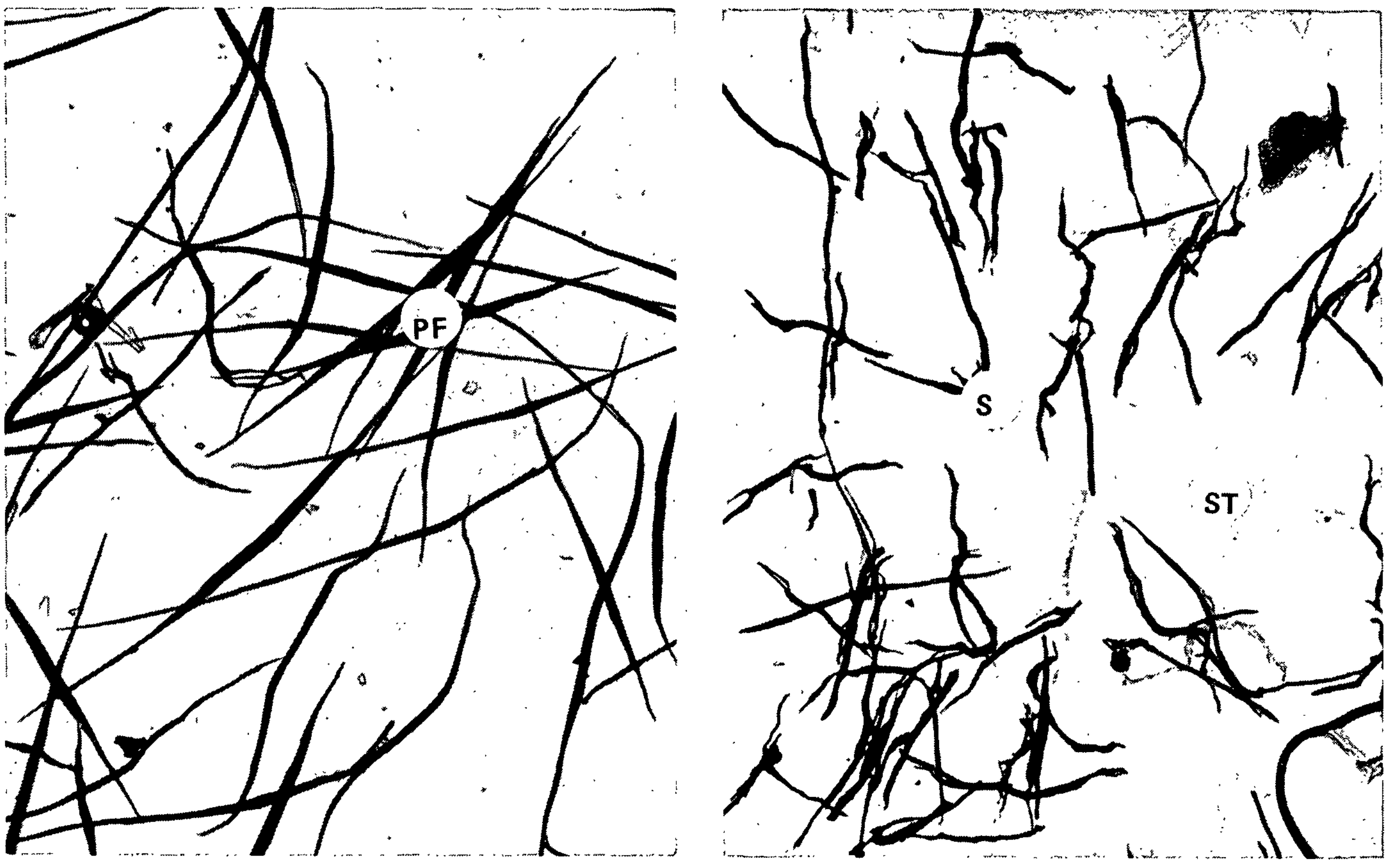


Figure 20. The 60-Mesh Screen (Left) Contained by Weight Principally Phloem Fibers (95+%). The 150-Mesh Screen (Right) Contained Principally Branched Sclereids (60-70%) with Some Sieve Tubes (10-20%). Magnification — 75X. Symbols Illustrate Phloem Fibers (PF), Sieve Tubes (ST) and Sclereids (S)

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, about 32 grams of solids will result. Of this 32 grams, about 5.9 grams (5.9%) of phloem fibers, 2.5 grams (2.5%) of sclereids and 0.6 gram (0.6%) of sieve tubes will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study was to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for silver maple samples collected July 17 (growing season) and December 13 (dormant season). After testing, the dormant season samples were examined to determine the location of the zone of failure. Figure 21 illustrates the zone of failure for silver maple during the dormant season. Wood/bark adhesion values averaged 14.1 kg/cm^2 and the failure zone was located in the secondary phloem in a more or less tangential line between sieve tubes, phloem parenchyma cells and phloem fibers located 0.5-0.6 mm from the cambium zone.

Another dormant season sample examined showed the failure zone occurring principally between cells in the dormant cambium zone immediately adjacent to the xylem. One small corner of the break extended further into the phloem and failure occurred primarily between phloem parenchyma and sieve tubes in the proximity of the cambium zone. The more typical location of failure probably is in the secondary phloem, however, a trend we have seen in most species examined thus far.

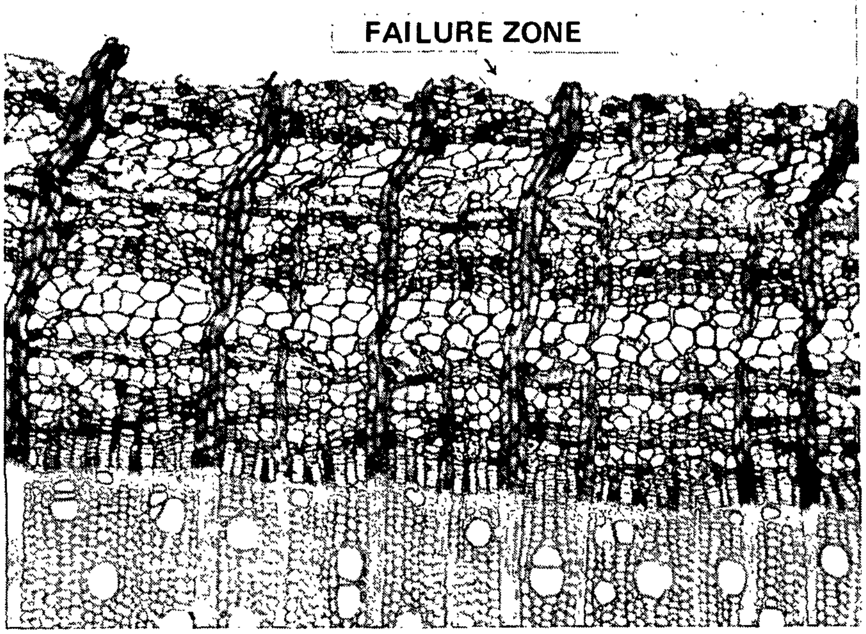


Figure 21. Illustrated is the Silver Maple Failure Zone on December 13. Failure in this Sample Occurred in the Secondary Phloem in a More or Less Tangential Line Between Sieve Tubes, Phloem Parenchyma Cells and Phloem Fibers Located 0.5-0.6 mm from the Cambium Zone. Magnification — 75X

Growing season adhesion values averaged 3.4 kg/cm^2 but the zone of failure was not examined microscopically. Growing season failure zones are quite consistently located in the cambium zone or the newly formed xylem elements just outside the cambium zone and have averaged between 3-6 kg/cm^2 for most species examined.

As a result of measurement data taken on the species included in Appendix Table XXX and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with silver maple.

High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXII summarizes the bark strength and toughness tests made on the wood and bark of silver maple. (Appendix Tables XXXII and XXXIII compare the modulus of elasticity of silver maple bark with other species examined in this project.)

TABLE XXII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF SILVER MAPLE[a]

Material	Strength	Toughness
Wood	--	0.50
Inner bark	3.4	0.17
Outer bark	--[b]	0.12

[a]Determinations average of two trees.
[b]Outer bark to thin to test.

Bark strength values for silver maple inner bark were low compared to other hardwoods tested thus far. No measurements were able to be obtained on the outer bark because of its thinness. Toughness values for both wood and bark were intermediate compared to other hardwoods tested. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the high specific gravity of the bark and the low strength and intermediate toughness measurements, it appears that hammermilling would work fairly well on this species.

Summarized in Table XXIII are the results of the hammermilling tests run on silver maple wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a very modest reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 4% wood loss and a 14% reduction in levels of bark. This is the lowest amount of

TABLE XXIII

SUMMARY OF HAMMERMILLING TEST ON SILVER MAPLE

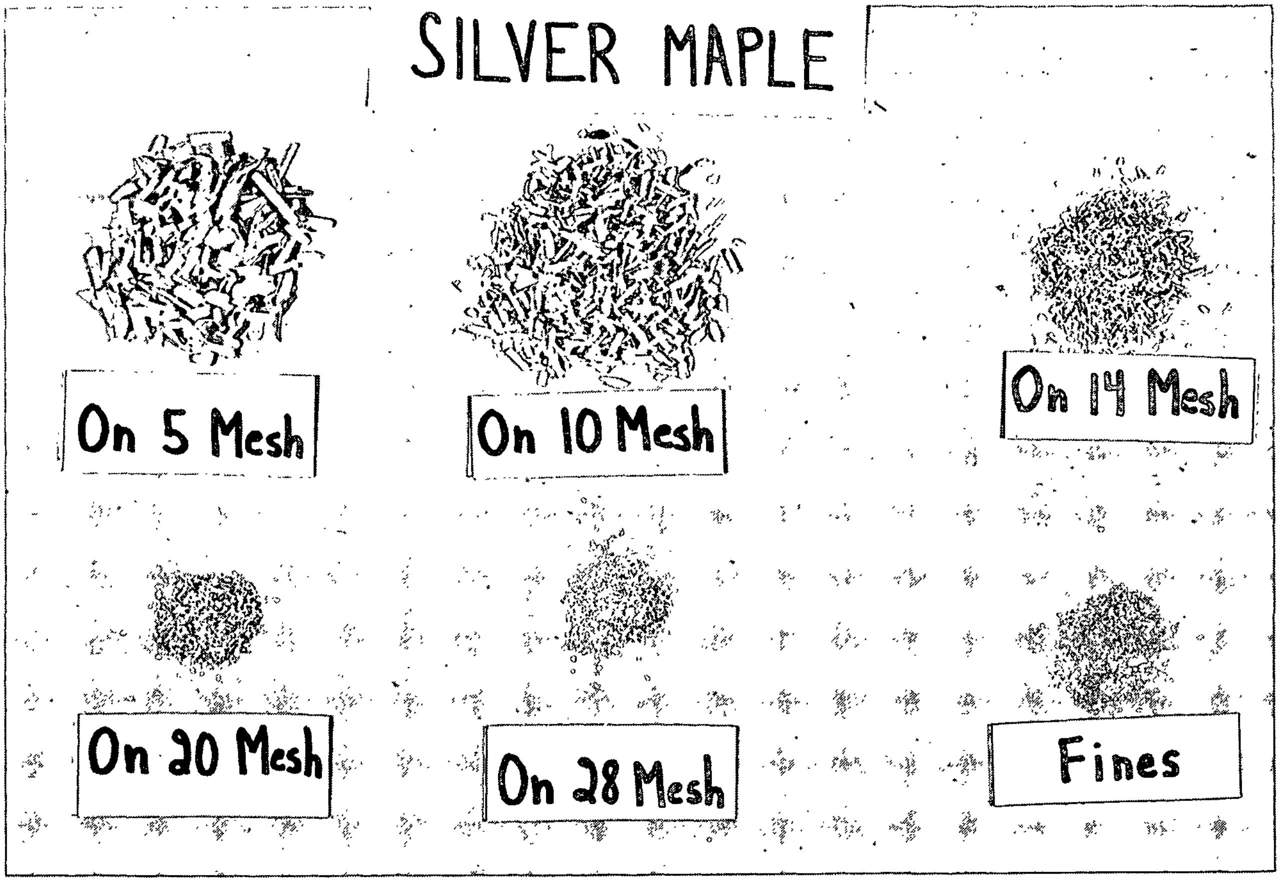
Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-11	Bark	57.8	21.9	5.9	2.7	2.8	8.9	Outer bark very thin layer and seemed to stay attached to the inner bark. Bark [illegible] stringy in appearance
	Exterior wood	61.5	28.0	6.5	1.6	0.9	1.5	
	Interior wood	59.0	31.4	6.2	1.6	0.8	1.0	
3212-12	Bark	43.8	33.7	8.1	3.7	3.7	6.9	Same as 3212-11
	Exterior wood	53.1	34.2	7.5	2.5	1.2	1.5	
	Interior wood	68.0	23.6	5.0	1.5	0.8	1.1	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

bark removed by hammermilling to date and, although the specific gravity, strength and toughness measurements predicted otherwise, the stringy shape of the bark probably was a factor in it being retained on the larger mesh screens. Another factor was the lack of outer bark, which tends to break up more under the hammermilling action, and which would be found on the smaller-mesh screens. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be increased (21% bark removal and 10% wood loss). It seems doubtful that a wood loss this high is justified in view of the fact that the bark removal is still so low. In addition, the bark contains a large amount of usable fiber. Figure 22 illustrates the effect of hammermilling on wood and bark of silver maple. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and re-screening. The fractions still remaining high in bark could be treated by some other method if desired. It is not possible to remove additional bark through improvements in screen design as the hammermilled bark has the same configuration as the wood. Summary Table XXVIII compares bark strength, toughness and reaction to hammermilling of silver maple with other species tested thus far.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.



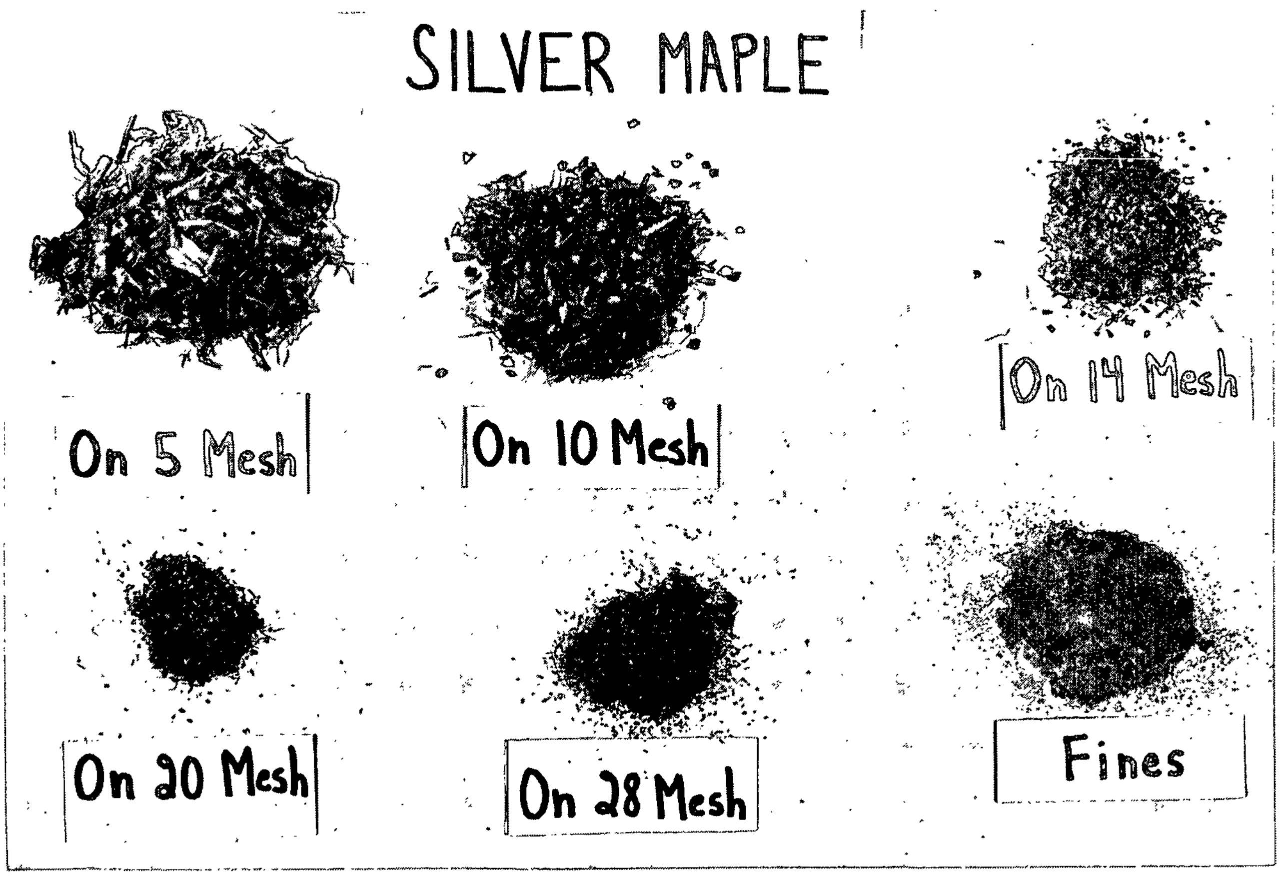


Figure 22. Illustrated is the Effect of Hammermilling on Silver Maple Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two silver maple trees (IPC 3212-11 and IPC 3212-12) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested, although the outer bark samples came from scattered areas in the bark which had thicker-than-normal outer bark. Inner, outer and total bark were all very close in density at the various moisture contents.

Figure 23 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

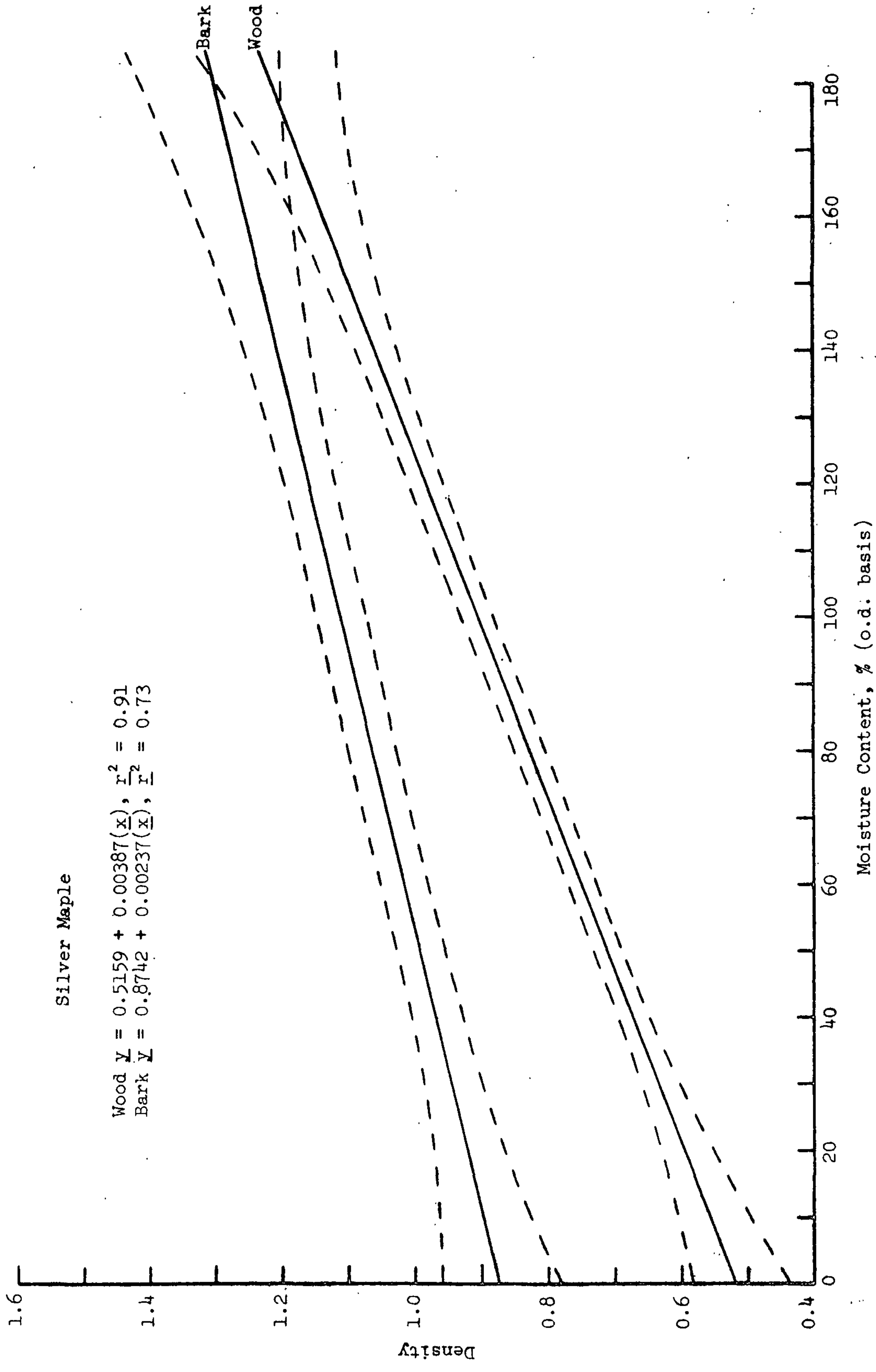


Figure 23. Illustrated is the Relationship Between Basic Density and Moisture Content for Silver Maple. The Dashed Lines are Two Standard Deviations Above and Below the Mean

mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation through water flotation is a technique that would have some success with silver maple. Bark chips would begin sinking at a moisture content of 40-50% and the wood would float up to about 115% moisture content (ovendry basis). Segregation would be possible between these moisture contents.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XXIV summarizes the results for silver maple. There was a small difference between the two trees in

TABLE XXIV

SUMMARY OF DWELL TIME RESULTS FOR SILVER MAPLE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-11	after 5	0	100
Bark	15	0	100
	60	12.1	87.9
	240	31.8	68.2
IPC 3212-11	after 5	0	100
Exterior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-11	after 5	0	100
Interior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-12	after 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-12	after 5	0	100
Exterior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-12	after 5	0	100
Interior wood	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

their flotation characteristics. The bark of silver maple is close to a density of 1 at 20% moisture content and the bark of tree 3212-11 must have picked up enough water in an hour to bring it to the point where it would begin sinking. Again, relatively dry wood and bark do not rapidly take up moisture and so could not quickly be segregated unless treated in some special manner or the original starting moisture content is near 40%.

DATA INTERPRETATION

Silver maple bark is low in extractives but does contain some sclereids. However, these sclereids are branched and separated, rather than the short, interlocking type, and should not cause a problem in paper. In addition, the bark contains usable fiber. All of these characteristics make the pulping of silver maple bark a possibility in certain instances. For every 100 grams of bark that is pulped 5.9 grams of fiber, 2.5 grams of sclereids and 0.6 gram of sieve tubes will be produced. Water flotation was the only segregation technique that had any promise among the several tried. Segregation appears possible at moisture contents of 40-50% up to 115%. Between these moisture contents, bark would sink and wood would float. Hammermilling gave rather poor results with only 14% bark removed and a 4% wood loss. Retained was the material on the 14-mesh and larger screens. The stringy shape of the bark after hammermilling and the lack of outer bark probably contributed to the poor results. However, it is possible that a quick segregation could be made by concentrating the bark in the small-sized chip fractions, hammermilling or shredding that fraction and rescreening.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (17), Hooper (18), Biltonen, et al. (19), Short, et al. (20), Miller (21) and Vais and Vostrov (22).

BARK FUEL VALUE, ASH, CALCIUM, AND SILICA LEVELS

FUEL VALUE

Rising fuel prices have prompted a closer look at the use of bark as fuel. For many end products, removal of the bark is necessary and utilization of bark as fuel is a partial solution to disposal of bark waste.

Listed in Table XXV are the Btu values of the species investigated thus far, both in terms of Btu's per ovendry pound and Btu's per cubic foot. Although values are quite similar when figured on the basis of Btu's per ovendry pound, the relative fuel value of the various species becomes more apparent when the specific gravity of the bark is taken into account and heating value is figured in terms of pounds per cubic foot. Also given in Table XXV are values found in the literature. In most cases, the values found in the literature have been converted to pounds per cubic foot for comparison with IPC values.

Chang and Mitchell (12) reported that the heating value of hardwood barks was lower than that of softwood barks. They found that the barks of all eight softwood species investigated had values greater than 8500 Btu's per dry pound and nine of twelve hardwoods had lower values. However, hardwood barks, on the whole, are higher in specific gravity than softwoods and, when this is taken into account by calculating the values on a cubic foot basis, the fuel value of hardwood barks is generally greater than that of softwood barks.

Fuel value is extremely sensitive to moisture content. Green wood of most species has about 60% of the heat value of well air-dried wood. For instance, a pound of oven-dried red oak wood with a calorific value of 8600 Btu's yields

TABLE XXV

BARK FUEL VALUES

Species	Total Sp.Gr.	Weight, lb/ft.^{3}	Btu/lb o.d. wt.	Btu/ft.^{3}	Literature Values, Btu, lb/ft.^{3a}
Quaking aspen	0.50	31.2	8,712	271,814	318,041 (35), 263,110 (12)
Sugar maple	0.54	33.7	8,426	283,956	299,572 (35), 246,044 (12)
White birch	0.56	34.9	10,332	360,587	371,160 (35), 329,247 (12)
Northern red oak	0.65	40.6	8,896	361,178	320,090 (36)
Southern red oak	0.70	43.7	8,371	365,813	349,250 (36)
Northern white oak	0.58	36.2	7,536	272,803	
Southern white oak	0.56	34.9	8,046	280,805	256,271 (36)
Eastern cottonwood	0.31	19.3	8,422	162,545	
Sweetgum	0.42	26.2	7,650	200,430	188,640 (36), 195,190 (12)
Yellow poplar	0.38	23.7	8,956	212,257	
Black tupelo	0.44	27.5	8,102	222,805	
Sycamore	0.60	37.4	7,978	298,377	
White ash	0.50	31.2	8,453	263,734	
Red alder	0.58	36.2	8,760	317,112	305,383 (39), 287,681 (12)
N. black cottonwood	0.40	25.0	8,765	219,125	225,000 (39)
Silver maple	0.57	35.6	8,360	297,616	
Loblolly pine	0.33	20.6	9,320	191,992	193,640 (37)
Slash pine	0.35	21.8	9,327	203,329	196,244 (12), 204,484 (37)
Douglas-fir	0.41	25.6	9,962	255,027	252,595 (38), 258,560 (39)
Western hemlock	0.45	28.1	9,297	261,246	262,735 (38)
Engelmann spruce	0.51	31.8	8,830	280,794	265,816 (12)
Lodgepole pine	0.38	23.7	9,382	222,353	241,503 (12)
Ponderosa pine	0.35	21.8	9,616	209,629	
Western larch	0.32	20.0	8,825	176,500	164,080 (12)
White spruce	0.39	24.3	8,913	216,586	241,399 (35)
Balsam fir	0.40	25.0	9,339	233,475	281,190 (35), 221,525 (12)
Jack pine	0.41	25.6	9,393	240,461	299,155 (35), 224,282 (12)
Red pine	0.27	16.8	9,070	152,376	
Shortleaf pine	0.35	21.8	9,310	202,958	208,190 (37)
Longleaf pine	0.45	28.1	9,290	261,049	256,553 (37)
Virginia pine	0.54	33.7	9,170	309,029	283,889 (39)
Black spruce	0.42	26.2	9,143	239,547	216,045 (12), 225,582 (35)

[a]Literature cited [Chang and Mitchell (32)] values based on airdry samples with an average moisture content of 6% (range 4.8 to 6.7%).

about 5700 Btu's when air dried and about 3400 Btu's when green (34). Figure 24, taken from data supplied by Cunningham and De Vriend (40) shows the drop in usable Btu's at increasing moisture contents.

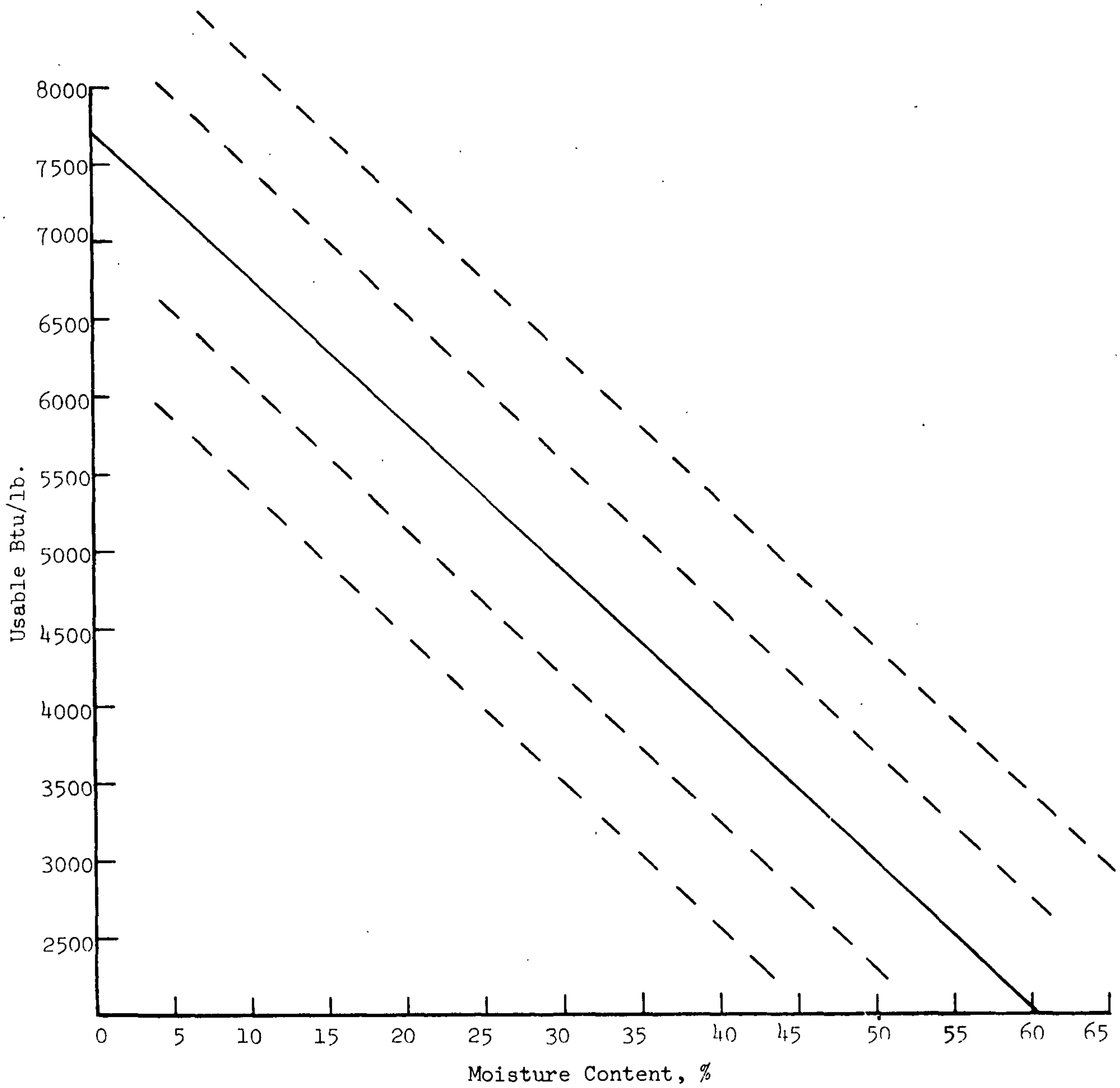


Figure 24. Illustrated is the Effect of Moisture Content on Usable Btu's per Pound

ASH, CALCIUM, AND SILICA LEVELS

Listed in Table XXVI are percent ash, calcium and silica on an oven-dry basis. Ash is the noncombustible part of the bark and needs to be removed, at least in part, after burning. According to Chang and Mitchell (12), a high percentage of ash tends to give lower heat of combustion values. Wood has a low ash content, generally less than 1% of dry weight (38). IPC ash values for bark ranged from 0.8% for loblolly and slash pine to 12.6% for northern white oak. Softwoods generally had lower ash values than did hardwoods. Also listed in Table XXVI are values obtained from the literature.

Calcium is one of the principal inorganic elements in bark. When bark is pulped, high levels of calcium can be expected to increase recovery system scaling problems. More rapid scaling increases evaporator down time and reduces heat transfer. Low percentages of calcium in bark are therefore desirable. Trends were the same for percent calcium with loblolly and slash pine again the lowest of the species investigated (0.2%) and northern white oak the highest (5.2%). Also, as with percent ash, softwoods generally had lower values than did hardwoods.

Insoluble silicates are naturally occurring minerals that are commonly found in soils. They include not only extremely hard and abrasive types of minerals but silicon as an element in clay minerals of soils. Silica (SiO_2) levels are of interest because, in the form of minerals, they represent the principal acid insoluble fraction in bark and, as such, are expected to remain as one possible abrasive contaminant in pulps.

TABLE XXVI

PERCENT ASH, CALCIUM AND SILICA IN BARK

Ovendry Basis

Species	Ash, %[a]	Literature Values, ash, %	Calcium, %	Silica, %
Quaking aspen	5.2	2.8 (12), 3.9 (35)	1.9	0.03
Sugar maple	8.3	6.3 (12), 5.0 (35)	3.0	0.19
White birch	2.4	1.5 (12), 1.7 (35)	0.7	0.06
Northern red oak	5.4	5.4 (12)	2.2	0.12
Southern red oak	6.5		2.6	0.14
Northern white oak	12.6	10.7 (12)	5.2	0.29
Southern white oak	8.2	10.7 (12)	3.4	0.42
Eastern cottonwood	6.2		2.5	0.18
Sweetgum	10.5	5.7 (12)	3.8	1.41
Yellow poplar	2.8		1.0	0.05
Black tupelo	7.3		2.9	0.11
Sycamore	7.1		3.0	0.06
White ash	4.4		1.6	0.13
Red alder	5.9	3.1 (12), 3.1 (39)	1.4	0.05
N. black cottonwood	5.0		1.1	0.08
Silver maple	3.6		0.6	0.18
Loblolly pine	0.8	0.4 (37)	0.2	0.09
Slash pine	0.8	0.6 (12), 0.7 (37)	0.2	0.04
Douglas-fir	1.2		0.3	0.06
Western hemlock	1.7		0.3	0.04
Engelmann spruce	2.6	2.5 (12)	0.8	0.08
Lodgepole pine	2.2	2.0 (12)	0.6	0.16
Ponderosa pine	0.7		0.2	0.16
Western larch	2.4	1.6 (12)	0.6	0.26
White spruce	4.2	3.5 (39)	1.2	0.14
Balsam fir	3.4	2.3 (12), 2.6 (35)	1.0	0.10
Jack pine	1.3	1.7 (12), 2.1 (35)	0.3	0.14
Red pine	1.3		0.3	0.03
Shortleaf pine	1.6	0.7 (37)	0.4	0.10
Longleaf pine	0.6	0.7 (37)	0.2	0.004
Virginia pine	2.2		0.7	0.01
Black spruce	3.1	1.8 (35)	0.8	0.10

[a]Ashed at 600°C.

The SiO_2 levels reported in Table XXVI are levels from bark samples which have been carefully harvested and transported and represent SiO_2 levels in bark relatively free from contaminating soil minerals. Some measure of silica levels (principally sand) that are added by harvesting and transporting could be obtained by comparing appropriately sampled and analyzed wood and bark samples from company operations with the relatively soil-free silica (SiO_2) levels reported in Table XXVI.

There has been greatly increased interest in bark Btu's, calcium, ash and silica content, resulting in a number of publications in this area. Additional publications of interest include those by Corder (39, 41), Junge (42-43), Howard (44), Johnson (45), Smith (46), Burnett (47) and Kowalczyk (48).

BETWEEN-SPECIES COMPARISONS

This section of the report provides an opportunity for the reader and the researcher to examine the data available to date and determine what useful interrelationships exist that will be helpful in improving our overall understanding of bark. Table XXVII (conifers) and Table XXVIII (hardwoods) provide a quick method of comparing the basic information available for the first 32 species investigated.

Considered in this progress report were one conifer (black spruce) and three hardwoods (red alder, northern black cottonwood and silver maple). The bark characteristics and strength properties of black spruce turned out to be fairly similar to those of white spruce and did not differ greatly from balsam fir. The one possible exception was the higher-than-normal dormant season wood/bark adhesion levels encountered for black spruce. Taking into consideration the similarity in bark characteristics between black spruce and white spruce, the detailed disscussion regarding between species comparisons for conifers that was presented in Progress Report Six (p. 116-122) remains valid and has not been repeated in this report.

For most species investigated, the hardwood barks were similar or higher in specific gravity than the conifer barks (Engelmann spruce, Virginia pine, eastern cottonwood and yellow poplar are exceptions). The specific gravity of the hardwood barks investigated show no consistent relationship to the specific gravity of the associated sapwood. For some species, the wood has a higher specific gravity, for others the bark has the higher specific gravity and there are several species, like gum and yellow poplar, where the specific gravity of the wood and bark is very similar. Conifer barks are generally similar or lower in specific gravity than the associated sapwood (Engelmann spruce was an exception). The

TABLE XXVII

WOOD AND BARK CHARACTERISTICS OF CONIFER PULPWOOD SPECIES

Characteristic	White Spruce	Balsam Fir	Jack Pine	Loblolly Pine	Slash Pine	Douglas-fir	Western Hemlock	Lodgepole Pine	Ponderosa Pine	Engelmann Spruce	Western Larch	Red Pine	Shortleaf Pine	Longleaf Pine	Virginia Pine	Black Spruce
Specific gravity (o.d. wt./green vol.)																
Wood	0.34	0.34	0.39	0.45	0.54	0.43	0.40	0.39	0.39	0.34	0.50	0.39	0.47	0.55	0.50	0.40
Total bark	0.39	0.40	0.41	0.33	0.35	0.41	0.45	0.38	0.35	0.51	0.33	0.27	0.35	0.45	0.54	0.42
Inner bark	--	0.32	--	0.29	0.34	0.42	0.46	0.32	0.34	0.41	0.37	0.20	0.26	0.25	0.27	0.33
Outer bark	0.43	0.46	0.43	0.34	0.36	0.40	0.45	0.45	0.35	0.52	0.33	0.29	0.35	0.48	0.56	0.46
Extractives, % (airdry)																
Wood	2.2	2.0	3.9	3.0	3.3	4.0	1.6	3.5	5.3	2.8	1.4	3.5	4.1	4.3	4.1	1.5
Bark	16.0	19.5	15.3	8.5	8.4	16.4	11.7	15.7	15.7	24.4	14.4	5.8	7.7	8.8	8.2	14.7
Density at 100% moisture (green wt./green vol.)																
Wood	0.70	0.75	0.79	0.88	1.10	0.815	0.80	0.89-0.92	0.96	0.80	1.43	0.74	1.10	1.20	1.08	0.84
Bark	0.83	1.07	0.83	0.57	0.72	0.825	0.85	0.74-0.95	0.62	1.14	0.61	0.62	0.72	0.90	1.03	0.97
Pulp yield, % (bark)	20.6	26.0	18.6	23.6	23.6	17.6	35.8	27.4	29.1	24.4	27.8	33.0	20.1	26.4	23.2	26.0
Usable bark fiber, %[a]	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0	0
Sclereids or phellem cells remaining, %[a]	1.5	12.0	<1	1	2	2	11	<1	1	3	0	<1	<1	<1	<1	3
Fiber location[b]	--	--	--	--	--	IB-OB	--	--	--	--	IB	--	--	--	--	--
Sclereid or phellem cell location[b]	IB-OB	IB	OB	OB	OB	IB-OB	IB-OB	OB	OB	OB	--	OB	OB	OB	OB	IB-OB
Wood/bark adhesion, kg/cm²																
Growing season	4.4	2.4	4.0	5.8	3.5	3.4	3.6	2.2	5.0	3.4	1.2	--	--	--	--	--
Dormant season	10.3	9.0	10.7	5.5	9.1	8.0	8.2	5.6	9.6	12.5	4.4	9.6	8.6	22.0[d]	7.2	18.1
Bark strength, kg/cm²																
Inner bark	--	1.7	2.3	3.7	6.4	5.8	6.0	--	4.6	--	4.5	--	7.4	--	4.6	10.6
Outer bark	7.4	1.4	2.3	3.2	5.2	3.0	--	2.4	4.9	4.2	4.4	5.6	2.7	5.8	4.0	7.6
Toughness																
Inner bark	--	0.06	--	0.10	0.06	0.34	0.12	0.10	0.10	0.24	0.12	0.16	0.16	0.21	0.30	0.22
Outer bark	0.16	--	0.07	0.06	0.09	0.03	0.10	0.08	0.08	0.16	0.10	0.12	0.10	0.10	0.16	0.10
Sapwood	0.34	0.42	0.34	0.54	0.54	0.58	0.28	0.28	0.26	0.26	0.28	0.60	0.94	0.89	0.61	0.45
Hammermilling[c]																
Bark removed, %	23	44	26	34	36	28	24	31	26	25	26	26	29	35	31	26
Wood loss, %	4	6	5	6	5	4	3	4	4	4	6	5	4	6	4	6

[a]Usable bark fiber and sclereids or phellem cells remaining are the fibers and sclereids retained on the 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.
[b]Major proportion located in either the inner bark (IB) or outer bark (OB).
[c]Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.
[d]Unusually high value, possibly due to sample condition.

TABLE XXVIII

WOOD AND BARK CHARACTERISTICS OF HARDWOOD PULPWOOD SPECIES

Characteristic	Quaking Aspen	Eastern Cottonwood	Sweetgum	Sugar Maple	White Birch	Northern Red Oak	Southern Red Oak	Northern White Oak	Southern White Oak	Sycamore	Yellow Poplar	Black Tupelo	White Ash	Red Alder	Northern Black Cottonwood	Silver Maple
Specific gravity (o.d. wt./green vol.)																
Wood	0.38	0.38	0.44	0.59	0.49	0.56	0.60	0.64	0.67	0.45	0.39	0.52	0.57	0.37	0.31	0.42
Total bark	0.50	0.31	0.42	0.54	0.56	0.65	0.70	0.58	0.56	0.60	0.38	0.40	0.48	0.58	0.40	0.57
Inner bark	0.40	0.29	0.51	0.69	0.57	0.53	0.68	0.65	0.70	0.60	0.38	0.37	0.51	0.55	0.38	0.51
Outer bark	0.55	0.32	0.36	0.49	0.54	0.71	0.70	0.52	0.44	--	0.42	0.37	0.43	0.62	0.42	0.61
Extractives, % (airdry)																
Wood	3.0	1.4	2.6	1.0	4.0	4.5	4.8	2.4	4.6	2.2	3.9	3.0	4.0	2.1	2.3	3.5
Bark	15	7.9	10.2	6	17	11	11.6	7.2	8.6	8.1	13.8	10.6	12.6	6.0	20.0	6.6
Density at 100% moisture (green wt./green vol.)																
Wood	0.79	0.84	0.84	1.24	1.01	1.06	1.25	1.30	1.38	0.98	0.79	0.88	1.20	0.77	0.63	0.91
Bark	1.15	0.81	0.87	1.08	1.16	1.18	1.39	1.05	1.13	1.21	0.82	0.85	0.95	1.15	1.04	1.11
Pulp yield, % (bark)	33.8	35.4	34.9	33.9	36.3	28.4	30.7	35.4	36.6	31.4	32.3	31.4	35.7	27.0	26.0	32.0
Usable bark fiber, %[a]	10	9	5	3	0	5	4	3	3	0	13	1-10	16	0	12	6
Sclereids remaining, %[a]	1	<0.1	--	0.2	0.7	0.2	--	--	--	--	0	0	0	0	0	2.5
Fiber location[b]	IB	IB	IB	IB	--	IB	IB	IB	IB	--	IB	IB	IB	--	IB	IB
Sclereid location[b]	IB	--	IB	IB	IB	IB	IB-OB	IB-OB	IB-OB	IB	--	IB-OB	--	IB	IB-OB	IB
Wood/bark adhesion, kg/cm²																
Growing season	6.4	4.4	10.2	5.8	5.1	2.5	5.4	4.8	--	--	--	--	--	--	--	6.1
Dormant season	11.4	13.5	15.3	10.1	12.0	8.4	8.2	7.8	7.2	14.8[e]	16.6	13.5	23.8	13.0	18.7	14.1
Bark strength, kg/cm²																
Inner bark	9.0	17.7	8.1	1.4	1.6	2.1	3.6	4.6	4.7[d]	6.1	13.4	9.6	20.0	8.2	13.9	3.4
Outer bark	4.9	4.2	5.2	4.7	9.8	4.6	3.4	3.2	--	--	10.4	10.5	4.2	5.9	7.3	--
Toughness																
Inner bark	0.22	0.14	0.20	0.25	0.10	0.13	0.11	0.16	0.12	0.15	0.20	0.20	0.45	0.10	0.10	0.17
Outer bark	0.10	0.11	0.11	0.10	0.10	0.18	0.14	0.10	0.09	--	0.18	--	0.20	0.02	0.07	0.12
Sapwood	0.45	0.38	0.28	1.20	0.68	0.93	0.55	0.62	0.98	0.50	0.23	0.56	0.68	0.50	0.30	0.50
Hammermilling[c]																
Bark removed, %	34	18	32	29	38	34	46	37	38	45	23	39	24	48	26	14
Wood loss, %	5	5	7	5	6	10	6	5	3	7	7	5	6	8	5	4

[a] Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.
[b] Major proportion located in either the inner bark (IB) or outer bark (OB).
[c] Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.
[d] Test mistakenly performed on total bark.
[e] Samples failed in tensile.

lack of a consistent specific gravity relationship in hardwoods makes the use of a water flotation procedure for mixed hardwood chips virtually impossible. Water quality considerations have also decreased the usefulness of this approach.

Hardwood barks, with the exception of sycamore, white birch and red alder, have varying levels of fiberlike structures in the bark. Conifers, in contrast, with the exception of Douglas-fir and to a lesser extent western larch, contain no fiberlike elements in the bark. These results suggest that most conifer barks, when pulped, should not be expected to produce fiber that will contribute to the strength of the paper and board being produced. There is also considerable evidence that the high amounts of thin-walled cells (sieve cells and parenchyma cells) produced when high levels of bark are pulped could result in paper machine drainage problems. Also to be considered when bark levels of 10-15% are being pulped are the economics of such factors as lower pulp yields, brightness, higher permanganate number and higher chemical consumption. Major monetary losses have been described when daily production is reduced by 10% because the mill is "digester-limited" and pulp production is decreased as a result of pulping wood/bark mixtures [Keays and Hatton (49)].

The fiber content of hardwood bark offers an interesting situation when some type of mechanical procedure is used to break up and remove the bark. The part of the bark that does not respond to this type of treatment is usually the stringy, fiber-rich bark. As a result, a procedure that removes much of the non-fibrous bark (usually outer bark) and retains for pulping the stringy bark that behaves like wood during mechanical treatment, could result in a fairly favorable fiber yield situation. White ash, black tupelo, yellow poplar, quaking aspen, eastern cottonwood, northern black cottonwood and shagbark hickory are examples of species that have been examined that could be a source of modest amounts of bark fiber.

There has been no consistent pattern with regard to level of bark extractives with the exception that the levels in the bark are from about three to eight times as high as in the wood. Browning (50) reported that mineral substances in the bark can be more than ten times higher than in the corresponding wood. Most conifer barks have higher levels of extractives than do hardwood barks. Red pine and the southern pines (slash, loblolly, shortleaf, longleaf, and Virginia) are the exception with extractives levels from only 5.8 to 8.8%. Aspen, northern black cottonwood and white birch are hardwood species with high levels of extractives and Engelmann spruce and balsam fir are the two conifers with the highest levels of extractives. Even with these latter species, because of the relatively thin bark involved on pulpwood-sized trees, pitch problems are not expected to be serious unless, as the result of concentrating large amounts of bark from screening procedures, high levels of bark are pulped. It is also important to remember that seasoning can diminish the content of extractives in bark and our values are based on airdry samples in most cases, rather than fresh samples.

Wood/bark adhesion during the growing season was low and very similar for all species investigated (except sweetgum). Quite consistently, the zone of failure occurred in the cambium zone or the newly formed nonlignified wood fibers adjacent to the cambium zone. Dormant season adhesion was, as expected, higher than growing season adhesion and the failure zone usually occurred in the partially mature sieve and parenchyma cells of the inner bark, just outside the cambium zone. Dormant season wood/bark adhesion tends to be slightly higher for hardwoods than for conifers and, in certain instances, seems to be associated with the presence of large numbers of phloem fibers in the inner bark. Medium-high dormant season adhesion was associated with intermediate levels of inner bark fibers in aspen, cottonwood, and black tupelo. High wood/bark adhesion was associated with high levels of inner bark fibers in yellow poplar, northern black cottonwood, white ash and shagbark hickory. Moderate levels of wood/bark adhesion in white birch and red alder and sycamore appear to be exceptions to the rule.

As discussed in Progress Report Seven, breaking the bond between wood and bark (separation) is an important first step in any segregation procedure. A very practical way of separating bark and wood during the growing season, and in some instances during the dormant season, is through the action of the chipper. Arola (51), working with northern hardwoods, found that chipper action during the growing season gave better results than during the dormant season with less than 2% bark remaining on the chips from 4-6 and 8-inch diameter bolts. Erickson (52) obtained similar results for spruce, balsam fir and jack pine. Results during the growing season were good; however, separation during the dormant season was poor (36-72%) for bolewood and even less for the thin-barked branchwood, with the poorest month of separation being November (36-48%). Erickson (52), working with maple, reported 96% separation during the chipping throughout the year. He also found better separation with winter-cut frozen wood over unfrozen bolts, although more fines resulted.

Despite the fairly consistent location of the wood/bark failure zone, there are, particularly in the dormant season, major differences between species in the ability of the chipper to cause separation. Preliminary Institute of Paper Chemistry investigations suggest inner bark strength and chipper knife impact on the cambium zone are important factors. For hardwoods, and possibly some conifers, the presence of fibers and sclereids in the inner bark influence inner bark strength.

Bark thickness and wood density (or frozen wood) influence chipper knife impact at the cambium zone. Chipper separation during the dormant season is expected to be least effective on thin-bark, low-density woods with fiber in the inner bark. White spruce, although it has no fiber in the inner bark, is an example of a thin-barked, low density wood in which dormant season separation is poor.

Mechanical treatment of bark continues to look promising as a method of upgrading low-quality chips high in levels of bark. The approach attempts to take advantage of the lower strength and toughness of bark with the result that there will be a reduction in the size of the bark particles sufficient to allow removal by screening. For hardwoods, when a hammermilling type action is employed, good bark removal seems to be best correlated with high specific gravity. For conifers, correlations between bark removal and strength properties are quite low. The most effective reduction in bark levels, particularly with hardwoods, results when specific gravity is high, bark strength and toughness is low and the bark is relatively thick. Northern red oak and red alder are examples where these relationships hold and the reduction in bark levels are higher than normal. When inner bark strength is high because of high levels of bark fibers, the stringy inner bark reacts like wood and is retained with the wood. Although such inner bark is classified as bark contamination, modest levels should have no adverse influence on paper properties.

Chip shredding is a technique that was developed about twenty years ago and has been used mainly with conifers that are cooked by the kraft pulping process. As described in Progress Report Five, (page 119), at least two pieces of commercial equipment have been used in shredding investigations (Jones Vertiflex and Sprout-

Waldron milling machines)[1]. Shredded wood chips have been described as giving increased yields, lower chemical consumption and either reduced cooking temperature and/or cooking times (53,54). As described in Progress Report Six, chip shredding was tried using a relatively high moisture content red pine sample. Using a procedure that involves retaining the material on two and four-mesh screens and using for fuel the material that was retained on or passed through the ten-mesh screen resulted in a 9% wood loss and a chip sample still containing 8% bark[2]. Northern red oak, in contrast, has a high wood and bark specific gravity, moderate bark toughness and strength and, when shredded and screened, had just a 5% wood loss and a bark contamination level of just 6%. These results look quite promising in view of the fact that the treatment has the potential for grit removal, much of the retained bark has a reasonable fiber content and the discarded material is a valuable source of energy.

Bark ash content, and calcium in particular, is of importance because of its apparent influence on recovery system scaling problems. Levels of ash (and calcium) in the barks of conifers are quite consistently less than in hardwood bark. White spruce, yellow poplar and white birch are exceptions. Calcium levels range from 0.2% in longleaf, slash, loblolly and Ponderosa pine to 5.2% in northern white oak. Since the levels in the bark are about 10-15 times as high as in the wood of most hardwood pulp species, pulping of whole-tree chips can be expected to increase recovery system scaling problems.

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[1]The Jones Vertiflex is manufactured by the Jones Division of the Beloit Corporation and the Sprout Waldron milling machine is produced by Sprout Waldron & Co., Inc.
[2]This information is slightly different than reported earlier because of a need to recalculate the results because of additional information obtained on the original bark input.

The fuel values of the bark of all pulpwood species investigated are summarized in this report. The ovendry Btu values for hardwoods vary more than for conifers. Our data for hardwood bark confirms Chang and Mitchell's (12) observations and indicate that there is a negative correlation between ash content and ovendry Btu values. This relationship is less evident for the conifers investigated. Both hardwood and conifer barks, when the Btu values are converted to a cubic foot basis, demonstrate fairly major differences. These differences are due to bark specific gravity differences. Values range from 152,780 for red pine and 162,500 for cottonwood to 365,800 Btu/cubic ft. for southern red oak. Western larch also had a relatively low value for a conifer (176,500 Btu/cubic ft.) while Virginia pine had the highest value (309,000 Btu/cubic ft.).

PLANS

The barks of 32 pulpwood species have been characterized in this project, including quaking aspen, sugar maple, white birch, northern red oak (Report One); loblolly pine, slash pine, Douglas-fir, western hemlock (Report Two); white spruce, balsam fir, jack pine, eastern cottonwood (Report Three); southern white oak, northern white oak, southern red oak, sweetgum (Report Four); lodgepole pine, ponderosa pine, Engelmann spruce, western larch (Report Five); red pine, shortleaf pine, longleaf pine and Virginia pine (Report Six); sycamore, yellow poplar, black tupelo and white ash (Report Seven); and black spruce, red alder, northern black cottonwood and silver maple (Report Eight). The issuing of Report Eight marks the end of the project as originally outlined. We have tentative plans, based upon company interest, to characterize several more species. In addition, we plan to summarize, in a special report, the overall findings of the bark characterization research.

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GLOSSARY

Basic density. Green weight divided by green volume.

Cambium. A cylinder, strip, or layer of meristematic cells, which divide to give cells which ultimately form a permanent tissue. The primary cambium in the stem and root gives rise to xylem and phloem, and the secondary one produces bark.

Dbh. Diameter breast height (4.5 feet).

Gelatinous fiber. Fiber, the inner wall of which is more or less gelatinous, or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark.

Paratracheal. Said of xylem parenchyma which occurs at the edge of the annual ring, around the vessels, but nowhere else.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die leaving a crust made up of alternate layers of cork and dead phloem or cortex.

Scalariform. Like a ladder.

Sclereid. See Sclerenchyma.

Sclerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elongated, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Secondary phloem. Inner bark.

Segregation. Removal of either the wood or bark fraction from wood/bark chip mixtures.

Separation. Detachment of bark from wood.

Sieve tube. A characteristic element of phloem. It translocates food materials synthesized in the plant. The cells are living, thin-walled and in longitudinal rows. They are connected by perforations in their transverse walls, through which pass strands of cytoplasm.

Specific gravity. Ovendry weight divided by green volume unless otherwise specified.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Suberized. Transformed into cork.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Tylose. A balloonlike enlargement of the membrane of a pit in the wall of a vessel or tracheid, and a xylem parenchyma cell lying next to it. It protrudes and blocks the cavity of the wood element.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vasicentric. Paratracheal.

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Wood. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers and some parenchyma.

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APPENDIX

TABLE XXIX

SAMPLE TREE INFORMATION

Species	Tree No.	Age, yr	Height, ft.	dbh, inch	Location
Black spruce	3212-91	59	51.5	7.0	Northern Wisconsin
	3212-92	60	49.0	7.3	Northern Wisconsin
Red alder	3212-105	37	70.0	7.9	Washington
	3212-108	36	78.0	8.0	Washington
Northern black cottonwood	3212-104	12+	72.0	9.5	Washington
	3212-109	28	62.0	9.0	Washington
	3212-116	13	--	7.7	Washington
Silver maple	3212-11	23	59.0	8.4	Greenville, Wisconsin
	3212-12	25	57.9	7.9	Greenville, Wisconsin

TABLE XXX

BETWEEN-SPECIES COMPARISONS OF WOOD/BARK ADHESION

Species	Wood/Bark Adhesion, kg/cm^2 Peeling Season	Dormant Season
Loblolly pine	5.8	5.5
Slash pine	3.5	9.1
Douglas-fir	3.4	8.0
Western hemlock	3.6	8.2
White spruce	4.4	10.3
Jack pine	4.0	10.7
Balsam fir	2.4	9.0
Lodgepole pine	2.2	5.6
Ponderosa pine	5.0	9.6
Engelmann spruce	3.4	12.5
Western larch	1.2	4.4
Red pine	--[a]	9.6
Shortleaf pine	--[a]	8.6
Longleaf pine	--[a]	22.0
Virginia pine	--[a]	7.2
Black spruce	--[a]	18.1
Shagbark hickory	5.3	26.9
Eastern cottonwood	4.4	13.5
Quaking aspen	6.4	11.4
Bur oak	5.8	9.6
White birch	5.1	12.0
Sugar maple	5.8	10.1
Northern red oak	2.5	8.4
Southern red oak	5.4	8.2
Northern white oak	4.8	7.8
Southern white oak	--[a]	7.2
Sweetgum	10.2	15.3
Sycamore	--[a]	14.8[b]
Yellow poplar	--[a]	16.6
Black tupelo	--[a]	13.5
White ash	--[a]	23.8
Red alder	--[a]	13.0
Northern black cottonwood	--[a]	18.7
Silver maple	6.1	14.1

[a]Growing season adhesion not measured.
[b]Samples failed in tensile.

TABLE XXXI

BETWEEN-SPECIES COMPARISONS OF BARK STRENGTH

Species	Bark Strength, kg/cm^2 Inner Bark	Bark Strength, kg/cm^2 Outer Bark
Loblolly pine	3.7	3.2
Slash pine	6.4	5.2
Douglas-fir	5.8	3.0
Western hemlock	6.0	--
White spruce	--	7.4
Jack pine	2.3	2.3
Balsam fir	1.7	1.4
Lodgepole pine	--	2.4
Ponderosa pine	4.6	4.9
Engelmann spruce	--	4.2
Western larch	4.5	4.4
Red pine	--	5.6
Shortleaf pine	7.4	2.7
Longleaf pine	--	5.8
Virginia pine	4.6	4.0
Black spruce	10.6	7.6
Shagbark hickory	25.0	72.7
Eastern cottonwood	17.7	4.2
Quaking aspen	9.0	4.9
Bur oak	4.5	7.0
White birch	1.6	9.8
Sugar maple	1.4	4.7
Northern red oak	2.1	4.6
Southern red oak	3.6	3.4
Northern white oak	4.6	3.2
Southern white oak	4.7[a]	--
Sweetgum	8.1	5.2
Sycamore	6.1	--
Yellow poplar	13.4	10.4
Black tupelo	9.6	10.5
White ash	20.0	4.2
Red alder	8.2	5.9
Northern black cottonwood	13.9	7.3
Silver maple	3.4	--

[a]Bark strength measured on total bark rather than inner and outer bark.

TABLE XXXII

MODULUS OF ELASTICITY VALUES[a]
HARDWOODS
kg/cm^2

Species	Tree No.	Wood	Bark Inner	Bark Outer
Northern white oak	1	19100	10400	6700
	2	42800	6700	2700
Sugar maple	1	31600	14000	3500
	2	43600	15900	3300
Quaking aspen	1	17000	14000	6500
	2	24400	8200	--
Northern red oak	1	23700	13500	10900
	2	34100	6800	7800
White birch	1	34200	6900	1900
	2	33400	8400	2200
Eastern cottonwood	1	33900	23200	4300
	2	48700	17900	7200
Silver maple	1	31500	32000	13900
	2	32600	25000	11500
Sweetgum	1	23400	21300	--
	2	32700	23400	13400
Southern red oak	1	45500	10700	8600
	2	36500	7400	5900
Southern white oak	1	52000	6900	4700
	2	41000	9700	5500
Black tupelo	1	39000	9400	--
	2	41300	15700	--
Sycamore	1	43300	9600	--
	2	30000	12100	--
Yellow poplar	1	35800	11000	7400
	2	22800	8800	7500
White ash	1	47600	15500	7100
	2	50400	19500	8200
Red alder	1	36200	12900	4400
	2	17500	11500	5300
Northern black cottonwood	1	15100	20100	6700
	2	19400	19200	10900
Silver maple	1	18700	28800	9800
	2	36400	37100	17100

[a]Values based upon 4-6 determinations. Dashes indicate bark was unable to be tested for various reasons.

TABLE XXXIII

MODULUS OF ELASTICITY VALUES[a]
SOFTWOODS
kg/cm^2

Species	Tree No.	Wood	Bark Inner	Bark Outer
White spruce	1	20600	--	12200
	2	29600	--	17300
Jack pine	1	25700	--	4400
	2	24600	--	3800
Loblolly pine	1	25200	6700	3800
	2	21200	6500	2100
Western hemlock	1	43300	12600	7000
	2	34900	13200	4400
Douglas-fir	1	42400	28200	--
	2	43100	21700	1000
Slash pine	1	33100	3400	1900
	2	29800	3300	1900
Balsam fir	1	35200	6200	--
	2	21600	7000	--
Engelmann spruce	1	21600	24500	--
	2	30000	25500	6700
Ponderosa pine	1	15200	6500	2000
	2	34800	5100	3700
Lodgepole pine	1	30100	6700	1900
	2	24700	25900	5300
Western larch	1	40900	10900	5300
	2	40800	31600	8100
Red pine	1	18600	25800	1800
	2	20000	28900	3100
Shortleaf pine	1	35900	14300	3100
	2	41800	25000	3800
Virginia pine	1	48100	37100	3700
	2	23000	30700	7800
Longleaf pine	1	49500	33900	3800
	2	42000	26200	5900
Black spruce	1	31400	30900	7000
	2	25100	25000	5900

[a]Values based upon 4-6 determinations except the outer bark for western hemlock tree #2 which is one determination. Dashes indicate bark was unable to be tested for various reasons.

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